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# Effects of navigation aids on human error in a complex navigation task

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# THESIS

**EFFECTS OF NAVIGATION AIDS ON HUMAN ERROR IN A COMPLEX NAVIGATION TASK**

by

Omer T. Arisut

March 2002

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This thesis investigates land navigators' performance differences in land navigation when different navigation aids are used. The question that this thesis attempts to answer is whether the use of Global Positioning System (GPS) in land navigation results in a performance dependency, and, if so, whether that dependency adversely affects performance. To address these questions an experiment was conducted to see if the use of GPS makes map and compass training obsolete.

The participants were divided into two training groups; map + compass navigation and GPS navigation. The experiment studied human performance differences, human error, and transfer of training while participants navigated using only GPS in the first part, and map + compass in the second part of the experiment.

The results suggested that map +compass training is always preferable. A map +compass native land navigator outperforms a GPS native land navigator when GPS is not accessible. This evidence suggests that a military land navigator, in particular, should know both navigation techniques and should be able to switch from one to the other without any hesitation.

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**EFFECTS OF NAVIGATION AIDS ON HUMAN ERROR IN A COMPLEX NAVIGATION TASK**

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Submitted in partial fulfillment of the
requirements for the degree of

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# ABSTRACT

This thesis investigates land navigators' performance differences in land navigation when different navigation aids are used. The question that this thesis attempts to answer is whether the use of Global Positioning System (GPS) in land navigation results in a performance dependency, and, if so, whether that dependency adversely affects performance. To address these questions an experiment was conducted to see if the use of GPS makes map and compass training obsolete.

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# I. INTRODUCTION

## A. PROBLEM STATEMENT

The question that this thesis attempts to answer is to determine if the use of Global Positioning System (GPS) in land navigation results in a performance dependency, and if so how this dependency adversely affects performance.

Navigation and navigation training have been studied by the Naval Postgraduate School (NPS) for several years. Navigation training is essential especially for land navigation using basic techniques, such as map, compass, and terrain associated navigation. In addition, virtual environments (VE) are very effective for navigation training, training which does not depend on environmental factors such as weather conditions or time of day. Moreover when trainees have to travel to a required area to navigate, VE is a good solution for difficulties in navigation training.

A common criticism is that GPS should make navigation training obsolete. GPS is a very easy to learn and useful navigation aid. Navigators can find their exact destinations in shorter times using GPS. Therefore, spending time on navigation training (conventional map and compass navigation) is questioned.

This thesis will study:

- How does navigation performance of a GPS native navigator compare to a map + compass native navigator when they have all navigation aids available?
- How does navigation performance of a GPS native navigator compare to a map + compass native navigator when GPS is denied.

## B. MOTIVATION

Land navigation is mainly based on personal training as well as the ability to use navigation aids, such as a map, a compass and GPS. The way the navigators are trained is of great importance in choosing the navigation method.

People generally choose the navigation aid with which they are most comfortable and most knowledgeable. This is the result of the training time and method spent on the navigation aid and the experience level.

Familiarity with the navigation tool minimizes the fear of getting lost while reducing any panic effect due to disorientation. Navigators should be able to change the aid they use easily and without any hesitation under different conditions.

Gaining navigation skill through map and compass training takes, of course, more time than gaining comparable skills through GPS training. The Army spends seven weeks at the Fort Sill Education Center in Oklahoma for advanced individual training, receiving extensive training that includes primarily map and compass.

Some authorities believe that this long training period can be reduced to a few weeks with the advantage of GPS since these tools are user friendly and less demanding on the navigator. If GPS capabilities were available and accurate at all times, there may be no need for map and compass navigation. However, GPS technology has some vulnerabilities that should be taken into account. For instance, GPS may function improperly or not at all, thus denying the user accurate position data.

Several years ago at an air show in Russia, a company called Aviaconvesia demonstrated a four-watt GPS jamming device that could jam GPS signals within a 200 nautical miles radius. The cost of this GPS jammer was $4,000.

Another weakness of GPS in today's technology is spoofing. This is a higher signal than the usual GPS signal, so GPS users receive these signals unaware of the inaccurate data. (Barness, 2001).

The first and most basic step for land navigation is dead reckoning, which means determining the direction of the destination point and walking in the direction by pace count. This is the simplest method that works very well in vegetation, poor visual conditions, such as darkness or fog. Terrain association is the next step in land navigation and is harder to perform, so it takes more time to learn, but it is more accurate and robust to error. Two questions to consider are what happens if GPS users encounter a situation in which they can not get accurate information from their devices or if GPS is not functioning for some reason. Can the users still find their way as in the map and compass users or do they fail to handle the situation?

## C. THESIS ORGANIZATION

Six chapters comprise this research:

- Chapter I – Introduction: Identifies the purpose and motivation behind conducting this research.
- Chapter II – Background: Provides information on GPS, navigating, transfer of navigation training to the real world, human error, human error classification, dealing with human error and the previous research conducted in this area.
- Chapter III – Implementation: Describes the treatments, ability classification, map and course preparation, and the main steps of the experiment.
- Chapter IV – Methodology: Describes the process and methodology employed during the development of the experiment.
- Chapter V –Experiment Results and Discussion: Analyzes the data and discusses the observed behaviors of the participants.
- Chapter VI – Conclusions and Future Work: Explains the conclusions and gives recommendations about possible future work.

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# II. BACKGROUND AND PREVIOUS RESEARCH

## A. OVERVIEW

A common criticism of map and compass navigation training is that GPS usage makes navigation training obsolete. With this new device, is conventional navigation training still required or is GPS sufficient as a navigation aid? The use of GPS in land navigation might result in a performance dependency and that dependency might adversely affect performance, which causes human errors.

This chapter addresses issues of navigating and transfer of training to show that good navigation training can be transferred to the actual navigation environment. The rest of the chapter covers human error including classification, causes, and management of human error to understand why these errors occur during navigation tasks and the means of reducing these errors.

## B. RELATED RESEARCH

### 1. Global Positioning System

Historically, determining the accurate location for artillery batteries and target elements so units could mass fires was the arduous task of the artillery survey. Survey teams were nomads on the battlefield operating during the day without higher level supervision and returning at night to report what they had done and seen determining where they were needed for the next day (Field Artillery, 2001). Their job was mainly land navigation including terrain association. The teams had accomplished their job if the units were able to mass fires accurately. Today we have instant electronic position locating devices called Global Positioning System (GPS) which reduce training time.

GPS was created to meet the more precise location information needs of the military. Although the first intent for the system was for defense purposes, in 1983 President Reagan ordered that it be made freely available worldwide for commercial use. This device consists of three basic elements: satellites, ground-based control centers and user receivers. From 1978 to 1994, a network of 24 satellites were launched to surround the globe. These satellites orbit every 12 hours, stationed 11,000 miles above the Earth. In total, there are six orbital planes, each containing four satellites. This provides between five and eight visible satellites at any point on Earth. On board each satellite are four atomic clocks, a communications receiver and a transmitter. Each satellite emits a continuous signal containing its exact location and time. The satellites are controlled by a system of tracking stations around the world.

The third part of the system is the user segment. There are hundreds of different types of GPS receivers. The basic elements are a receiver tuned to satellite signals, a processor, software to decode and analyze the signals, and a user interface designed for the specific application.

For a GPS receiver to determine its position, it needs to receive signals from at least three satellites, preferably more. The receiver takes the time data received from a satellite and, by comparing it with its internal clock, knows how long it took the signal to reach it. It then converts the time into distance determining how far away it is from the position transmitted by the satellite. By analyzing the data from three or more satellites, the receiver triangulates its position.


Figure 2.1 GPS Receiver

To be able to navigate with the GPS, the exact locations of the destination points should be either previously recorded in the GPS or the latitude and the navigator should know the longitude of these locations. To record a point in the GPS there are two methods. The first one is recording the current location when actually on the exact location, the other is recording a new point if the lat-long of the point is known. The rest is just choosing the destination from the GPS menu and following the direction arrow on the GPS while navigating the distance GPS indicates. As the navigator walks to the destination, the remaining distance and the direction will be updated from the satellites every a few seconds.

During Operation Desert Storm, for example, more than 9,000 commercial handheld units were distributed to the troops, letting them maneuver at night or in sandstorms when the enemy was unable to do so. The British and French crews digging the English Channel tunnel used GPS receivers to ensure that the tunnel met properly in the middle (Robb, 2000).

Instead of a simple map, compass or survey, the systems used today as a result of technology for land navigation or a artillery survey or job are very useful and simple to use; however, they are all susceptible in some way to manipulation by the enemy. The artillery community today has a deep belief and confidence in GPS technology, so they want GPS to be available at all times. In today's technology GPS can function improperly or may not work at all. There are still some modernization efforts to make GPS more reliable and robust, but also there are some counter studies against GPS. This device is susceptible to jamming. The satellite signal needed to operate GPS is very weak, so it can be easily jammed. It is nearly the same strength of a 100-watt light bulb emitting 300 miles away. An entire industry exists that develops GPS jammers allowing anyone to buy these devices.

At the previously mentioned air show in Russia, a company called Aviaconvesia demonstrated a four-watt GPS jamming device capable of jamming GPS signals within a 200 nautical miles radius. The cost of this GPS jammer was $4,000.

Spoofing the GPS is also possible in today's technology. This is a higher signal than the usual GPS signal so GPS users receive these signals unaware of the inaccurate data. (Barness, 2001).

Today many countries' transportation relies on GPS. The Transportation and Defense Departments sponsored a study called "Vulnerability Assessment of the

Transportation Infrastructure Relying on Global Positioning System". The study was released on September 10, 2001. The aim of the study was to see the reliability of GPS for U.S. transportation. According to the study, GPS is susceptible to unintentional disruption from atmospheric effects and communication equipment, as well as deliberate disruption. The study recommended (Vasishtha, 2001):

- Creating awareness among the aviation, maritime and surface user community of GPS' vulnerability.
- Implementing systems to monitor, report and locate unintentional interference to GPS.
- Assessing the applicability of military GPS technology to make it available for civilian use.
- Identifying backup systems and developing low-cost systems as backups to GPS.
- Continuing the ongoing GPS modernization program.

**2. Navigating**

Navigation is the theory and practice of navigating, which means to make one's way or to follow a planned course. Navigation or wayfinding performance improves with increased spatial knowledge of the environment. There are three sub-items of spatial knowledge.

- *Landmark knowledge* is information about the visual details of specific locations in the environment.
- *Route knowledge* is built by connecting isolated bits of landmark knowledge into larger, more complex structures.
- *Survey knowledge* is configurational or topological information.

In experiments designed to see whether landmark, route, or survey knowledge were associated with map reading, Levine drew three conclusions that are the basis of map design theory (Levine, Jankovic & Palji, 1982; Levine, Marchon & Hanley, 1984).

- The two-point theorem states that a map-reader must be able to relate two points on the map to their corresponding two points in the environment.

- The alignment principle states that the map should be aligned with the terrain. A line between any two points in space should be parallel to the line between those two points on the map.
- The forward-up principle states that the upward direction on a map (assuming it is mounted perpendicular to the floor) must always show what is in front of the viewer.

The primary issue in map design theory is that the map be congruent with the environment. This allows the viewer to quickly identify his current position and orientation on the map and, consequently, in the environment. (Levine, et al, 1982; Levine, et al, 1984)

### 3. Transfer of Training

Transfer of training is an important issue in navigation training. A good navigator is expected to show in the actual environment what he/she learned in the training phase. A person mainly trained for map and compass navigation is more likely to perform better than someone who is not trained.

To see the spatial information transfer from virtual environment (VE) to real environment (RE) an experiment was designed by Wilson, Foreman and Tlauka (1997). They wanted to find out whether learning spatial information in a VE is transferable to the real world. In their experiment, they had three groups: control group, VE group, and RE group. In the test phase, participants were required to do a pointing task and then a drawing task for different objects. The participants who became familiar with these objects in the exploratory phase were encouraged to guess the location of these previously shown objects. In addition, the researchers had the "Euclidean distance estimating task", and the "route estimating task". As a result of the experiment, they showed that spatial information can be transferred from VE to RE.

Another study by Banker (1997) was designed to see the effects and value of VE for terrain familiarization of unknown environments. He compared a VE only group to a map only and RE only condition in a RE navigation task. He did not use building interiors and urban environments; instead he focused on natural environments. The experiment designed by Banker was based on the sport of orienteering. He used 1:5000 scale maps instead of 1:15000 scale maps used in official competitions. As the experiment area was obviously smaller he needed more detail. He had three groups as VE, RE, and map only group as the control group. Banker also had three different ability levels of people in these three groups: beginner, intermediate, and advanced level. The VE group was trained in the VE, the RE group in the natural environment (the RE), and the control group just on the map. The participants were allowed to explore the area in their own group environment before the testing phase. Following this, they were tested for the number of map and compass checks they needed, off route errors, average plan, and route off distance errors. It was found that ability level had an important effect on performance and it was even more important then the training method. Intermediate level users benefited most from the VE training than either advanced or beginner level users. The VE training did not have time compression so it allowed more area to be traversed in shorter time than RE.

The fidelity of the training environment to the real task environment plays an important role in the transfer of training. There is a positive correlation between the amount of training transferred to the real task environment and the fidelity of the training environment. It can be said that if the training and the task-performing environment are the same, the transfer is the highest. “Greater degrees of physical fidelity are needed where physical or manual tasks are required” (Caird, 1996). Also, individual differences have great influence on overall performance and transfer also depends on these individual differences including ability. If individual differences are not taken into account and measured, some training effects might be hidden.

In applications such as nuclear power plant maintenance, workers are required to be professionals who are not expected to make errors. It is obvious that these workers need to be very well trained before working in the real environment. The highest fidelity environment for such training can be the environment itself, but any error may result in a large number of lost lives and huge amount of cost; therefore, this method is not very plausible. For a better training system rather than using books and monitoring the current employees, Schlager, Mumaw and Hoecker (1993) decided upon a VE training system for nuclear power plant maintenance applications. In their study they focused on applying tools for the design of VE training systems. They were confident about the role that VE simulation could play. With the help of VE, “trial-and-error” is to be avoided in the actual environment. The high cost of training would also be reduced by this new system. Greater transfer of training was also another aim of this study.

Kozak, Hancock, Arthur, and Chrysler (1993) designed a “transfer of training from virtual reality” experiment to study the value of real environment training versus VE training. In the experiment participants were asked to perform pick up and place tasks for aluminum cans placed in front of the participants. The cans were placed six inches from each other. The placing task required placing the can in the target locations. There were control, VE, and RE group in the experiment. The control group did not have any training. VE training group had the training in the VE, RE training group in the RE and then all groups performed the tasks in the RE. The results indicate that they could find no significant difference between the control group and the VE training group. RE training group was significantly better than the other groups. This study shows that a poor designed VE training system may have no effect in the positive transfer of training, and as a second conclusion it can be said that for very simple tasks or the tasks that have cheaper real world training, there is no need to design a VE training system. VE is just a tool that has to be used only when necessary.

## 4. Human Error

Peters (1966) defines human error in the following way: “Any significant deviation from a previously established, required or expected standard of human performance.”

A more appropriate definition for human error and one that is used in this thesis is “An inappropriate or undesirable human decision or behavior that reduces or has the potential for reducing effectiveness, safety, or system performance.” (Sanders & McCormick, 1993). There are two important points in this last definition. An action can be called an error because of its undesirable or potential effect on the system criteria or possibly on people’s safety. A second important point is that an error that is corrected before causing any trouble is still an error because it has the potential of adverse effect on human or system criteria. Human errors that are probable in a navigation task might be life threatening for a military navigator. Zero error is the top performance that a navigator can reach.

## 5. Human Error Classification

Human error classification is an important issue that facilitates understanding the probable error types in the current environment under specific circumstances. Understanding the possible error types helps to design better training programs, which increase the rate of training transfer and quality of navigation.

Being aware of the human error types might reduce its effects. Errors can be classified in terms of information processing and discrete actions. When information processing is required in a task, some steps are necessary in achieving the task; these are observation of the state, hypothesis formulation and testing, goal choosing, procedure selection for the goal, and execution of the procedures. This classification is more suitable for the operation of complex systems such as power plants.

The second error classification scheme is "discrete action classifications" which is more suitable for our navigation experiment.

- *Errors of omission*: An employee is electrocuted while trying to figure out the reason of failure in a machine because he forgot to disconnect the power cord. This is an error of omission that involves failure to do something.
- *Errors of commission*: These errors involve performing an action incorrectly. An example of such an error is while waiting for the green traffic light a person shifts into "R" instead of "D" crashing into another car.
- *Sequence error*: This involves performing actions or tasks out of sequence. A winch operator overturned the winch because he rotated the boom first with a heavy load rather than lifting the load first and then rotating it.
- *Timing error*: This is the failure to act in the allotted time period, due to performing either too slow or too fast. Being too slow to remove the hand from a work piece in a drill is an example of kind of this error.

Navigation errors are more likely to be considered as "errors of omission" and "errors of commission".

## 6. Human Error Causes

The causes of human error are possibly due to the environment, bad training, navigation aids, or personal reasons. This section will discuss these issues.

The work environment influences the psychological climate of the human. The changes in human beings are sensitive to the changes in external conditions. Such external conditions can be air temperature, humidity, air movements, radiant heat exchange, illumination (brightness, contrast, light intensity), noise and hours of work.

- *The influence of physical characteristics*: Physical characteristics sometimes play an important role in causing errors. The variables of this heading include age, experience, gender, health and physical fitness, alcoholism and drug use, intelligence, perception and motor ability, personality and emotional effects.
- *Overload*: In a given state overload occurs when mismatching load with the person's capacity. This mismatch can cause an overload or underload and both are dangerous. A human being cannot help but commit errors under overload conditions. Overload can be thought of in terms of physical, psychological or physiological load.
- *Decision to error*: Human beings at times act carelessly. The reason behind it might be the "person's current motivational field" which causes him/her to make an unsafe decision or the person's mental condition which leads him/her to cause an accident.
- *Traps*: Traps can be physical or mental. Physical traps are due to the design of the workplace. Incompatibility is a mental trap meaning that the environment a person is working in might be incompatible with what the person is used to or with his/her physique.

## 7. Dealing With Human Error

What can be done to reduce human error and how can we deal with navigation errors? This section discusses how to select a navigator, how to train, and how to design the training model or the environment.

Since human error is expected, some of these errors are considered better than no errors at all in the context of training when looking from the efficiency perspective.

Errors have positive effects in learning. Correct responses can be learned easily when some errors occur. Workers can explore the limits of the system by causing errors. Nevertheless, the goal should be to minimize the potential damage of errors and its likelihood. The following are some good strategies:

- *Selection*: Matching the correct person with the correct job or task is always important for higher efficiency or less human error. Selection of people having the required skills or capacities will decrease the error rate. Perceptual, intellectual and motor skills are the important ones to be considered.
- *Training*: More training improves the level of knowledge. Some errors occur because of a lack of knowledge, so more training reduces the number of errors as well as the kinds of errors. Additionally the way people are trained is very important; inefficient training may cause problems and negative transfer of training will probably occur. Therefore, adequate and proper training is necessary for less error rates.
- *Design*: A proper design of the working environment, system and the equipment may play an important role in preventing error and improving a person's performance. Designs can be considered as exclusive designs (making it impossible to make errors), preventive designs (making it difficult to make errors but not impossible), or "fail safe designs" (Sanders & McCormick, 1993).
- *Rules and assistance*: Both rules and assistance show the designers' solution choices. By following these rules more errors can easily be prevented while reducing the need for safety violations.

# III. IMPLEMENTATION

## A. TREATMENTS AND ABILITY CLASSIFICATION

Two groups comprise the treatments within the study. Both groups have six people so there were 12 participants in total. Selecting participants for this study might have changed the results seriously thus all the participants were novices in land navigation with no previous experience. This selection factor is important for the study as it is also investigating the transfer of training. To reduce the influence of the physical and psychological characteristics, all the participants were chosen in the age group of 25-27, with the same level of experience, with no physical problems, and with the same level of education (all graduate students). Although all the participants were novices some individual capability and skill differences were possible; therefore, randomly placing the participants might have yielded better skilled participants in the same group. In order to have approximately the same skill level, the participants were required to take the "UC Santa Barbara Spatial Knowledge and Ability" questionnaire at the beginning of treatments. The questionnaires were graded and participants were grouped as poor, weak, good, or excellent in spatial orientation.

Each question in the UC Santa Barbara questionnaire had seven choices between strongly agree and strongly disagree: strongly agree 1 2 3 4 5 6 7 strongly disagree. An answer including four had a value of zero. An answer agreeing with the positive sense of direction had values of 10, 6, 3 respectively with 1, 2, 3 while answers representing a negative sense of direction had values as –3, -6, -10 respectively with 5, 6, 7. After each question was graded cumulated points were on a [-150, 150] scale. Scores were grouped according to the following intervals: [-150, -76] poor, [-75, 0] weak, [1, 75] good, [76, 150] excellent. Every participant was put in one of these groups and then he/she was assigned to a group thus balancing the number of similar skilled people in both groups. After this study the participants were appointed either to map + compass or GPS group.

## B. THE MAP AND THE COURSE

Both the training and the experiment fields were in the Fort Ord Military area. This area was closed to motor vehicles, which was an important safety issue for the experiment. The only possible danger was the cyclists in the area. The area immediately northeast of the junction of Gigling Road and Watkin's Gate Road was selected for the training course. This area was 800 by 600 meters in size of gently rolling forest, meadow and thicket. There were some jeep trails and narrow trails crisscrossing. The area had different altitude levels. An initial survey was conducted to determine the area's suitability in size and vegetation for the training session. This survey took about six hours. After considering the suitability of this area the original 1:24000 scale Fort Ord military map was scanned to give the training field map in 1:5000 scale. In 1:24000 scale no detail could be seen. The area was surveyed to determine the locations of each checkpoint and the route between each of them. The length and the azimuth of each leg connecting one checkpoint to another were carefully determined. Next, the real field was checked and measured to see if the design including the angles and distance on the map fits one to one to the real environment. Some minor changes were made for a perfect design to prevent human error due to bad map design. The simplicity of the legs increased from start to final checkpoint. At times, the trails themselves were the routes and sometimes they were not. Some details not on the 1:24000 scale map were also noted. Each checkpoint location was stored in the GPS.

## C. FAMILIARIZATION

Each individual in both groups was given a briefing about general navigation techniques and the vegetation in the Fort Ord area. They were also shown the poisonous oak and advised not to touch it. Another precaution given to the groups was encountering cyclists in the area especially while navigating on the paths. After that, they were equally familiarized with navigation aids, which were map, compass, and GPS in our study. The familiarization with navigation aids included the following topics. These topics and their associated training materials can be seen in Appendix E.

- Elements of a Map
- Scale Reading of a Map.

- Colors Used in Maps and their Meanings.
- Map Symbols
- Contour Lines
- The Use of the Map.
- Elements of a Compass.
- Magnetic Variation.
- Orientation of Map with a Compass.
- Pace Counting.
- Route Selection.
- Attack Point.
- Elements of a GPS.
- GPS Features.
- General Navigation Errors.

This session lasted for about an hour, since the familiarization phase had more detail than needed in the experiment phase. The reason for this was the benefit to the participants giving them a better view of navigation after which participants responded to a test of eight questions. All the participants were open to learning new materials, expressing the importance of navigating in a real environment for the first time. At that stage they all knew only how to navigate with just a GPS *or* with map + compass.

Another important step was pace counting. For this every participant was required to walk a pre-measured straight route on a flat asphalt road that was 0.1 miles long counting his or her every left step. Therefore, each participant's walking distance was recorded by pace count. After the pace counting session the distances between checkpoints in the azimuth distance chart were converted to pace counts.

Regardless of group, each participant received the same familiarization task. They were taught how to orientate the map and compass and how to read a map (like signs, directions, distances, heights etc.), how to handle and read a compass, and how to point an object in a particular direction. They were also asked to go to an azimuth at a specific number of paces. As a result, they learned the basics of map and compass usage. This was followed by the GPS familiarization in which they were taught how to use GPS, and how to go to a destination already pre-stored in the GPS. At this stage, they were familiar with both GPS and map + compass but they were considered “native” to whatever they were taught in depth (their group assignment).

## D. TRAINING

In the training phase each participant in the map and compass group was asked to find the checkpoints one after the other, following the path given on the 1:5000 scale training area map as well as the azimuth and distance chart. There were four main checkpoints and multiple in-between checkpoints between the main ones. The trainer walked a few steps behind the participant to observe his/her behavior when an action was right or wrong.

Since the familiarization and training sessions were just one hour long, this amount of time was not adequate for perfect map reading and judging the azimuth and distances from the map as a result. To help the participants and also prevent the calculation errors at the design phase, participants in the map + compass group were asked to use the azimuth and distance chart in addition to map and compass. With this chart participants could read the azimuth and the distance needed to walk from their current location to the next destination.

The GPS group, unlike the map + compass group, was instructed to find each checkpoint and in between checkpoints just with the GPS. They knew how to choose the next stored destination point from the GPS by what they had learned in the familiarization session. They were taught not to change directions very often because of the update latency of the GPS. They were also taught to choose the next destination point from the GPS while facing the same direction they walked prior to stopping. Otherwise the arrow of the GPS would have shown the wrong direction before the next update.

Facing somewhere else rather than the previously traveled direction caused the participants to walk a distance before they realized they were heading in the wrong direction. After a few checkpoints they became efficient at navigating with the GPS. In addition to its simplicity, the GPS was also fun to use because the participants did not have to worry about pace counting and getting lost. They could choose any route without obstacles walking again in the direction the GPS showed. As navigation with GPS was easier than navigating with map + compass, the training session for the GPS group lasted for less than an hour. Everybody in this group was able to find all the checkpoints in a shorter time than the map and compass group with the map, compass and azimuth distance chart.

## E. THE EXPERIMENT

The field chosen for the experiment was just across the training field on the southeast of the junction of Gigling Road and Watkins Gate Road. There were nine main checkpoints in the experiment session. Between the main points there were different numbers of in between checkpoints. The main points had "I" shaped objects. These wooden objects were built for the experiment and given as visual signs to the subjects. All of the subjects expressed enthusiasm when finding these signs. The in between checkpoints did not have particular visual signs, but were chosen as some building remains. This was done especially to observe human error based on design issues (physical traps). The aim was to make the participants believe, at least to some extent, that the in between checkpoints also had some kind of visual signs. The experiment had two sessions: GPS session and the map + compass session. Each group was expected to perform the task better than the other group while navigating in their "native" session (GPS group is expected to do better in the GPS session and the map + compass group in the map + compass session). These same groups were also expected to be more self confident while navigating with their native navigation aids. None of the participants were told about the experiment goal and the experiment sessions in detail. So at the beginning participants did not know that there were two different sessions in the experiment.

These two sessions were common for all the participants regardless of their group. The first five main checkpoints were reserved for the GPS session. This session started at the start point and each participant was only given the GPS as the navigation aid and they were, therefore, required to find each point.

While the participant was navigating, they were followed from some distance behind to observe their behavior, and record their timing for each checkpoint with a stopwatch. When they made off-route errors (walking in a different direction) for more than 10 meters unable to correct their errors, they were instructed to stop and return to the original path. These errors were recorded as the participants navigated. At each checkpoint a participant stopped the stopwatch and reported their position at the designated point. The distance errors at each checkpoint (including the in between ones) were recorded in terms of meters. If a participant had an error, he/she was shown the original point and asked to return. This correction at every checkpoint prevented cumulative error with each navigation task being independent from the previous one.

The GPS session of the experiment was composed of five main checkpoints while the in between checkpoints included sixteen in total in this first session. The cumulative distance navigated was 1090 meters with this distance being a straight distance between each checkpoint.

It was normal for the GPS group to begin with the GPS because they thought that all the points would be found just with GPS. The GPS group did well in the first session. The map + compass group performed satisfactorily with the GPS in the first session. Although previously advised that it was very easy to navigate with the GPS, the map + compass group spent more time than the GPS group for the task. The GPS group was observed to be more confident and comfortable with their first step because they did not change their direction of heading when arriving at a new point. However, the map + compass group did not pay much attention to the latency of GPS position update, causing them to sometimes change their heading. Since the GPS showed an incorrect direction (not actually wrong, but when a new point is requested from the GPS, it assumes that its heading is the same since the last update. Thus any change at the last moment causes a wrong direction). The map + compass group did not realize direction until the next update (About 10-15 meters of walking). Furthermore too frequent incorrect direction changes made the map + compass participants wander around for some time making them nervous. The GPS group rarely had such a problem.

At the fifth checkpoint, the participants were told to change the GPS with map and compass, completing the rest of the experiment with these tools. The map and compass group were comfortable with the change because they figured at some point they would alter the navigation aids after being trained mainly for map and compass navigation. Thus this group took the new aids and proceeded with the task. Alternatively, for the GPS group, the response was different. Since the GPS group expected to complete the whole experiment with GPS, some participants in the GPS were not comfortable changing tools. They were concerned about getting lost without GPS. The expected level of discomfort was observed and noted.

This part of the test consisted of finding four main checkpoints and in between checkpoints. Although at first sight, the map and compass session had less main checkpoints than the GPS session, it had 29 total checkpoints and 1889 meters of navigation. Therefore, the second part was longer. The GPS group hesitated in starting the navigation. The participants' expressions and behavior showed some level of concern. Orientating the map and compass together and finding a way through the forest area was a concern for them initially. Some participants also forgot to count paces and had to start again. After two main checkpoints the GPS group got used to the map and compass and performing better in the remaining course. One more important detail with the GPS group was their uncertainty of the location of the checkpoints. They expressed doubt when reaching each checkpoint. The map + compass group did not have such a problem.

The GPS group preferred not to check the compass and read the values from the azimuth and distance chart; they very rarely looked at the map. Some participants in the GPS group only remembered to use the map at the eighth main checkpoint. The map + compass group used the map at every checkpoint to double-check their current location. They also corrected themselves by just checking the map. They used the terrain association information, which reduced their error rate. The GPS group preferred to go through the forest area, but the map + compass group usually preferred to go around the forest area by making 90 degree left and right turns. The dead reckoning training was transferred positively to the experiment from the training field. The self-confidence level was higher in the map + compass group.

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# IV. METHODOLOGY

## A. EXPERIMENT OVERVIEW

An experiment was conducted testing whether navigators are affected by the training method. The experiment further questioned whether GPS is an adequate navigation aid on its own or whether it needs to be supplemented with a map and compass. The other aim of the experiment is to observe human errors by the participants during the land navigation using different navigation aids. This section provides an overview of the experiment, while subsequent sections describe the tools, phases, and the methodology of the experiment in more detail. The general sequence of the experiment was the in-briefing, the ability classification "UC Santa Barbara Spatial Knowledge and Ability" questionnaire, the navigational methods and navigation aids' familiarization, training, and the experiment.

## B. PROTOCOLS

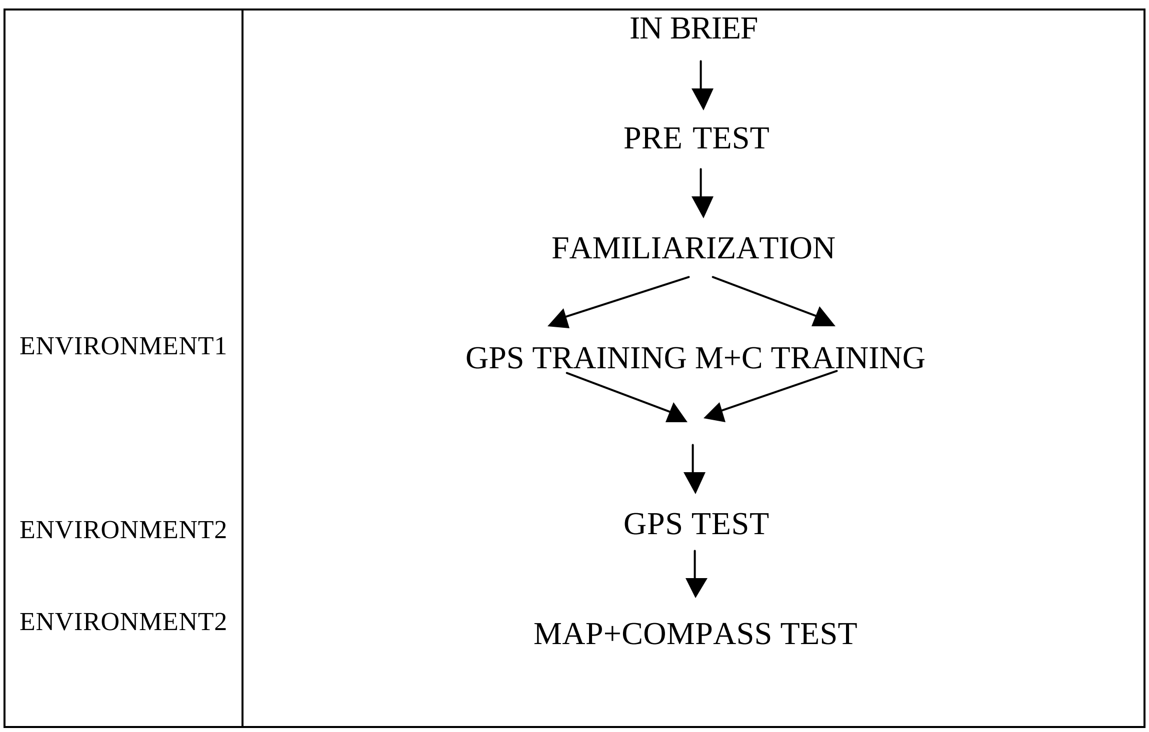


Figure 4.1 Experiment Protocol

The experiment consisted of two participant groups and two experiment phases. The two phases were land navigation with GPS phase, and land navigation with map and compass. These two phases were the same for both participant groups.

Participants were taken to the Fort Ord military area for the training and experiment in groups of at most two or one by one. The basic **in-briefing** was given to the participants who filled out and signed consent forms. This in-brief is shown in Appendix B and the consent forms are in Appendix C.

After the in-briefing, the participants were asked to fill out the “UC Santa Barbara Spatial Knowledge and Ability” questionnaire, using their answers to classify groups according to their abilities. This was the **pre-test** of the experiment.

After the ability classification the participants were familiarized with navigation methods, navigation aids, and pace counting. A pre measured distance of 0.1 miles on Gigling Road was used to measure the pace count of each participant. Participants walked this distance counting every left and right step. This information was then used to indicate the number of paces to be walked between each checkpoint using the map and compass navigation. In the navigation methods and in navigation aids familiarization each participant was given color printed navigation notes including details about the maps, compasses, GPS, their features, usage, and combined use. Participants were also familiarized with the navigation aids by holding them and navigating for some distance. The **familiarization** task was identical for both participant groups. All participants learned about GPS, the map, the compass, and basic navigation techniques. Familiarization notes in Appendix E were used in this session.

The next step was **training**. In the training phase, the map and compass group participants were asked to find the checkpoints as numbered on the 1:5000 scale training area map (Appendix G) as well as the azimuth and distance chart (Appendix F). There were four main checkpoints with multiple in-between checkpoints between the main ones. The trainer walked a few steps behind the participant to observe participant behavior and to advise on correct responses based on navigation techniques and the usage of navigation aids.

The GPS group, unlike the map + compass group, was instructed to find each checkpoint and in between checkpoints which were pre-stored in the GPS. Additionally they were taught some details of GPS navigation, such as not changing directions very often due to update latency of the GPS. They were also taught to choose the next destination point from the GPS while facing the same direction previously walked before stopping; otherwise, the arrow of the GPS showed the incorrect direction before the next update.

After the training was completed, each participant was taken to the experiment field just across the training field southeast of the junction of Gigling Road and Watkins Gate Road. The first session of the experiment was the **GPS test**. Both group participants performed land navigation just with GPS. Navigation times from one checkpoint to another were recorded as task completion times. Off-route error was the other data observed and recorded during this phase. No distance errors could be observed due to the ease of GPS usage. The general behaviors of the participants were also noted.

After completing five main checkpoints, the **Map + Compass Test** of the experiment began. Participants changed navigation aids and completed the remaining four main checkpoints with the map, compass, and the distance azimuth charts. The map of the experiment field can be seen in Appendix G. Task completion times, off-route and distance errors, and participant behaviors were again observed and noted for each checkpoint. The experiment was the same for both groups. All walked the same distance and performed the same tasks.

## C. EXPERIMENTAL DESIGN

A "2x2 between subject" design was used. All of the participants performed the navigation tasks in each session. Each participant navigated the checkpoints in the same order.

### 1. Participants

The participants for this experiment consisted of 12 individuals (1 female and 11 males) ranging in age from 25 to 27. One was a civilian and the others were active duty Naval officers. None of the participants had prior knowledge of the purpose of this study. None of the participants had prior experience in land navigation. None of the participants had physical difficulty with walking. Data were collected from 15 August 2001 to 03 October 2001.

### 2. Independent Variables

The controlled variables were the navigation methods and the experiment groups.

- **The GPS Session.** Navigating the first five checkpoints including the in between checkpoints using only GPS as the navigation aid.
- **The Map and Compass Session.** Navigating the last four checkpoints including the in between checkpoints using map, compass and the distance azimuth charts as the navigation aid.

| | **Experiment Groups** | | **Navigation Aids** | | | | | |
|---|---|---|---|---|---|---|---|---|
| Testing Sessions | GPS Group | M+C Group | GPS | Map | Compass | Distance Azimuth Charts | Pace Counting | Physical Objects |
| GPS Session | YES | YES | YES | NO | NO | NO | NO | YES |
| M+C Session | YES | YES | NO | YES | YES | YES | YES | YES |

Table 4.1. Independent Variables of the Experiment

The GPS session of the experiment had five main checkpoints with the in-between checkpoints totaling sixteen. The cumulative distance navigated was 1090 meters. This distance is the straight distance between checkpoints. The distance navigated changed somewhat for every participant since they made left and right turns on the route. In the GPS session participants navigated sometimes on paths and sometimes in forest area. This prevented the expectation of easy navigation on paths alone. Some physical objects were chosen as in-between checkpoints but not for all. This was intentional in order to see the effects of design on human error.

The participants navigated in this session just by using the GPS. They chose the next destination from the GPS and followed the GPS arrow to this direction.

The map and compass session of the experiment had four main checkpoints with the in-between checkpoints totaling twenty-nine. The cumulative distance navigated was 1889 meters. This distance is again the straight distance between checkpoints. The distance was the shortest distance the participants were expected to navigate. Like the GPS session, participants navigated sometimes on paths and sometimes in the forest area. Some physical objects were chosen as in between checkpoints but not for all. Navigation in this phase included using a map, a compass, and the distance-azimuth charts. Participants had to count their paces to ensure the distance they navigated.

### 3. Dependent Variables

The main goal of the experiment was to observe and measure human performance, human error, and the transfer of training when participants used different navigation aids, including those trained for and those not trained for. A number of measurements were used in order to determine the difference in performance levels of people in different navigating conditions. The participants of both groups were asked to navigate in each condition.

| TASK | DEPENDENT VARIABLES |
| --- | --- |
| NAVIGATION IN GPS SESSION | Task Completion Time |
| | Distance Error |
| | Off-Route Error |
| | Observed Behavior |
| NAVIGATION IN M+C SESSION | Task Completion Time |
| | Distance Error |
| | Off-Route Error |
| | Observed Behavior |

Table 4.2 Dependent Measures of the Experiment

#### *a. Task Completion Time*

The time to navigate from one checkpoint to the next checkpoint is measured in seconds and noted as task completion time. The time to find the next checkpoint from the GPS or map-compass orientation is also included in this time.

### *b. Distance Error*

The distance errors at each checkpoint (including the in between ones) are recorded in terms of meters. The distance between the current final position of the participant and the original checkpoint is determined as the distance error. In the GPS session, no distance errors were observable due to the ease of finding a particular point using the GPS.

### *c. Off-Route Error*

Navigating in a different direction with an angle of 45° or more for more than 10 meters is recorded as an off-route error. Parallel navigation to the original path is not an error.

### *d. Observed Behavior*

The behaviors of the participants such as hesitation, panic, being anxious or nervous are recorded in both sessions.

## D. APPARATUS

### 1. Test Environment

Both the training and the experiment fields were in the Fort Ord Military area. The training field was northeast of the junction of Gigling Road and Watkins Gate Road. This area was 800 by 600 meters in size of gently rolling forest, meadow and thicket. The experiment field is just across the training field southeast of the junction of Gigling Road and Watkins Gate Road. This area was 1100 by 550 meters in size of gently rolling forest, meadow and thicket. Both areas were closed to motor vehicles, which was an important safety issue for the experiment. The only possible danger was the cyclists in the area. The cyclists were informed and warned about the participants and warning signs were attached to the trees. The bigger size maps of both areas are shown in Appendix G.

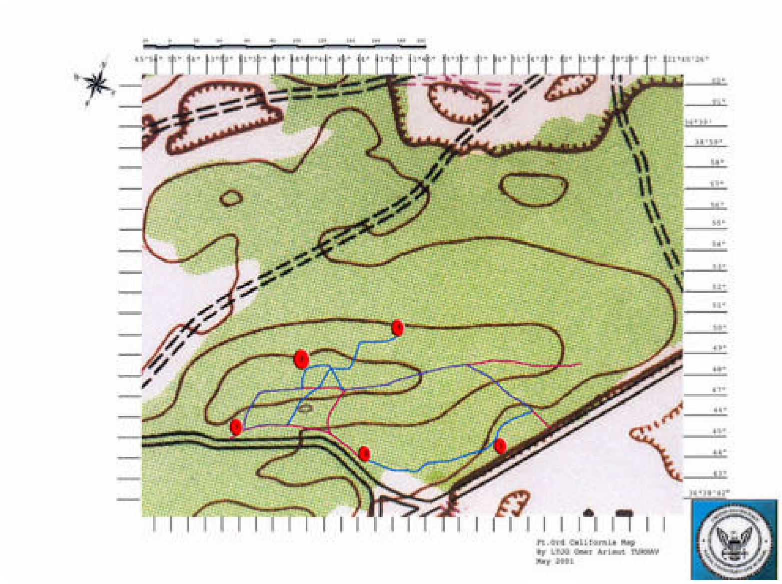


Figure 4.2 Training Field Map

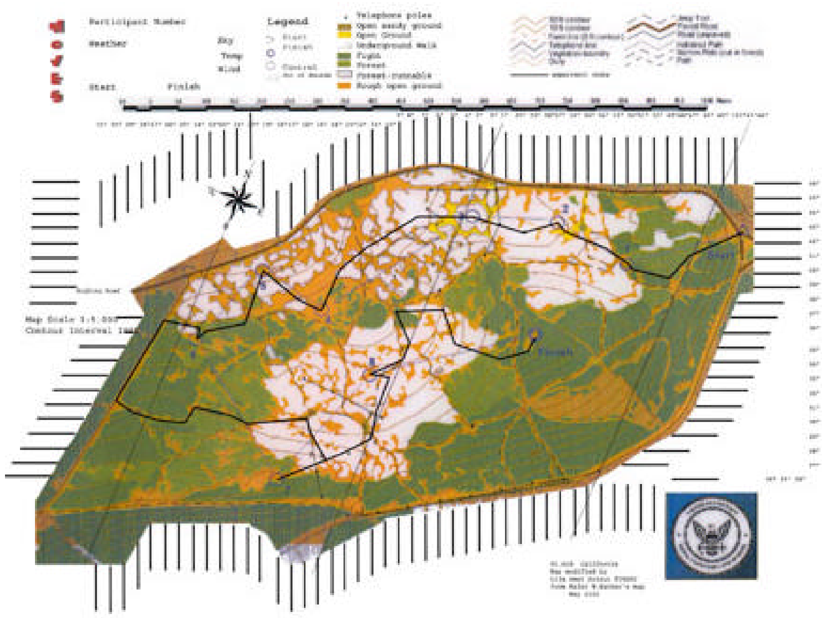


Figure 4.3 Experiment Field Map

**2. GPS (Global Positioning System) Receiver**


Figure 4.4 GPS Receiver

The Garmin GPS II Plus handheld GPS device was used for the GPS session of the experiment. Checkpoints were prerecorded in the device and participants were asked to find these points using it.

**3. Compass**

Military compass model C0110 GI was used for the experiment. This model is the regular compass used by the army. It has degree markings of +/- one degree and a lensatic eyepiece, which is suitable for sighting point to point.

Figure 4.5 Military compass

### 4. Stopwatch

A Casio HS-3-S1 stopwatch was used to measure the task completion times of the participants.

### 5. Adobe Photoshop 6.0

Photo editing software Adobe Photoshop 6.0 was used to design the maps of training area and the experiment area.

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# V. EXPERIMENT RESULTS AND DISCUSSION

## A. GENERAL INFORMATION

The main goal of the experiment was to observe the effects of navigation aids and the transfer of training on human error in a navigation task. A number of quantitative data were collected to see the differences in the performance and error levels of participants in two different navigation conditions. This chapter first describes the data analysis and explains the results. Next, it discusses the observed behavior of the participants.

### 1. Primary Hypothesis

The navigation performance of the individuals in each group will correlate with their “native” trained navigation aid. That is, the GPS group should do better in the GPS condition and the map + compass group should do better in the map + compass condition.

### 2. Data Analysis

The results of the experiment are presented as box plots and histograms. Participants performed two main navigation tasks. The first session/task of the experiment was performed using GPS as the navigation aid. The second session/task of the experiment was performed using a map and compass as the navigation aid. Primary analysis was based on task completion times in two different sessions. The other analyses were based on distance error and off-route error in two different sessions. The analyses were done in two different approaches. The first approach was the analysis of the data collected from the same session but different groups, and the second approach was the analysis of the data from the same group but different sessions. Since the distances between checkpoints varied greatly, task completion times were also very different in the two different sessions. Thus, in order to analyze the data from the same group but from different sessions, task completion times were normalized. For the analysis of the data from the same session but different groups, normalization was not required. For the distance error and off-route error analysis there was no need for normalization. No distance error was performed in the GPS session by either group. Since the GPS showed the exact point, the distance error analysis was only based on comparison of the two groups in the map + compass session. Off-route error was recorded on the basis of how many times a participant performed this error during a task. No data normalization was needed.

### 3. Power Analysis

An $\alpha$ value of 0.05 was used to determine significance. A post hoc power analysis for large effects, $\alpha = 0.05$, was made. The resulting power $(1-\beta)$ was 0.3224. The power of a test is defined as $1-\beta$, and $\beta$ is the probability of falsely accepting $H_0$ when in fact $H_1$ is true. Since this value is lower than 0.5 the chance to make a type two-error in the data analysis carried out can be said to be very low.

## B. RESULTS

### 1. GPS Session Results

#### *a. Task Completion Times for Each Checkpoint*

The time to complete the navigation task performed by GPS, from one checkpoint to another was measured for both experiment groups. For this analysis the task completion times for six people in the same group are averaged for each GPS session checkpoint. Differences in the task completion times were monitored for all 16 checkpoints in the GPS session for both groups. Figure 5.1 shows the task completion time averages for each group in the GPS session.

According to the two-sample t test there is no significant difference between the average group performances in GPS session on the basis of task completion times' means. $T_{0.05\ ,\ 15}=1.697$, $t= -1.199$ $p= 0.119$. $H_o: \mu_1 - \mu 2 =0$, $H_a: \mu_1 - \mu 2 <0$, $H_o$ is not rejected since -1.199 is not < -1.697. A Wilcoxon Rank-Sum test also fails to indicate any significant difference between the group performances on the basis of task completion times' means $H_o: \mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 <0$. $H_o$ is not rejected since p value 0.1486 > 0.05.

Although average GPS group task completion time is less than the average M+C group task completion time, both analyses fail to yield any significance difference between group performances.

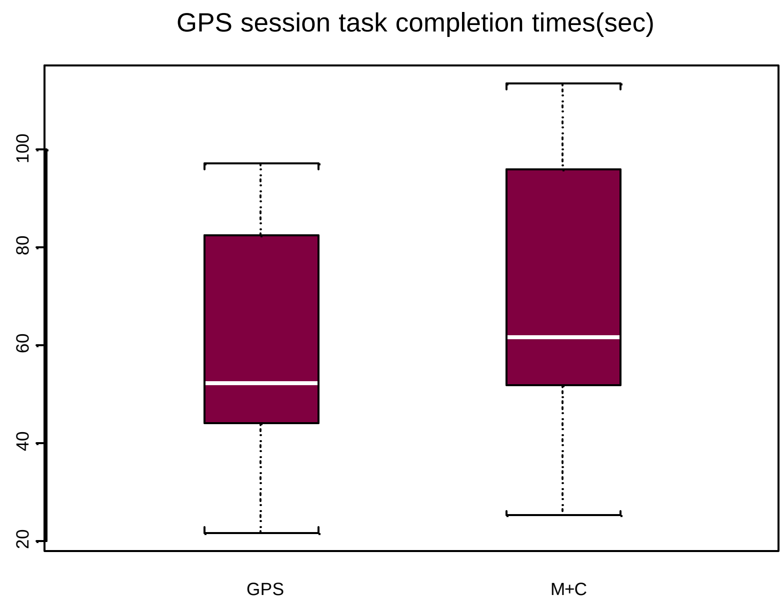



Figure 5.1 GPS Session Average Task Completion Times Group Boxplot Comparison for Each Checkpoint.

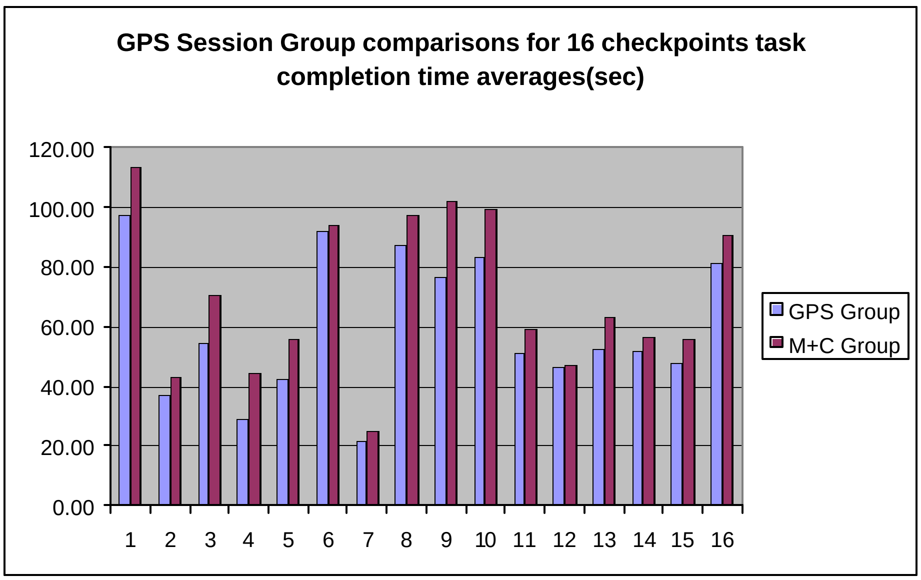
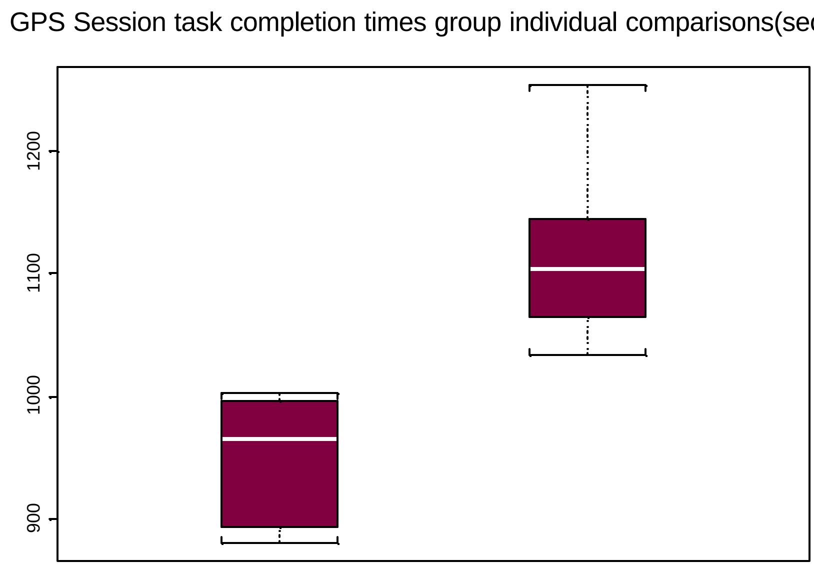



Figure 5.2 GPS Session Task Completion Times By Each Group for Each Checkpoint

### *b. Total Task Completion Times for Each Group Individual*

The total time to complete the navigation task performed by GPS was measured for both experiment groups. Monitoring for any significant difference in the total GPS session task completion times for both groups was part of this measuring. The analysis was based on the six total individual task completion times for each group. Figure 5.3 shows the total task completion times by each group individual in the GPS session.




GPS M+C

Figure 5.3 GPS Session Total Task Completion Times Group Individual Boxplot Comparison

According to the two-sample t test there is a significant difference between the group performances on the basis of individual task completion times' means. $T_{0.05, 5}=1.812$, $t= -4.453$ $p= 0.000614$. $H_o:\mu_1 - \mu 2 =0$, $H_a:\mu_1 - \mu 2 <0$. $H_o$ is rejected since $-4.453 < -1.812$

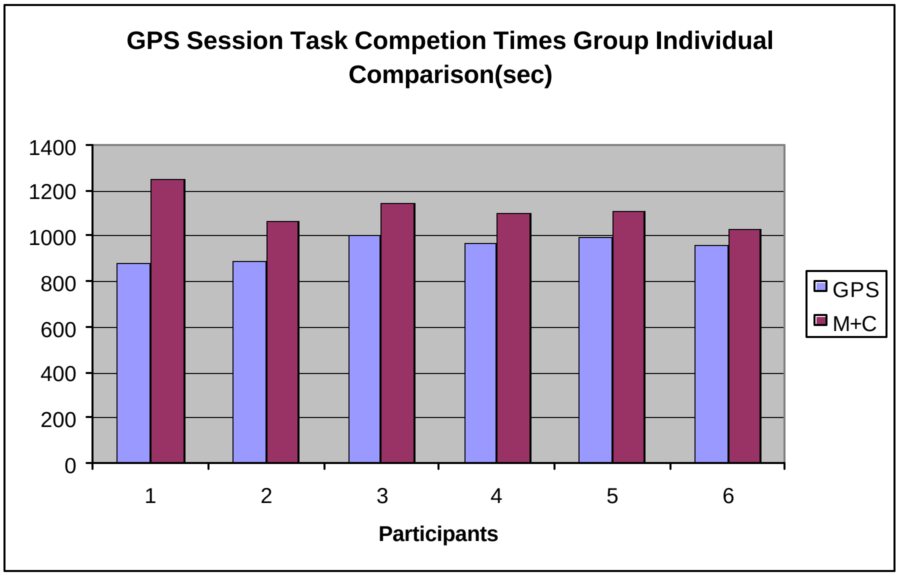



Figure 5.4 GPS Session Total Task Completion Times Group Individual Comparison

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis of individual task completion times' means, $H_o: \mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 < 0$. $H_o$ is rejected since p value $0.0022 < 0.05$. On the basis of total task completion times we can say that GPS group individuals showed a better performance than the M+C group individuals in the GPS session of the experiment.

***c. Distance Error for Each Checkpoint***

There was no distance error recorded in the GPS session for either group. GPS showed the exact checkpoint and prevented such an error.

***d. Distance Error for Each Group Individual***

There was no distance error recorded in the GPS session for either group. GPS showed the exact checkpoint and prevented such an error.

***e. Off-route Error for Each Checkpoint***

The off-route errors performed by each individual during the navigation task performed by GPS were observed and noted for both experiment groups. Each group was expected to error less in the session in which they were mainly trained. For this analysis, the off-route errors for six people in the same group are summed for each GPS session checkpoint. Any significant difference in the GPS session total off-route errors for both groups was monitored. The analysis was based on the 16 off-route errors totals for each group. Figure 5.5 shows the total off-route errors for both groups in the GPS session.

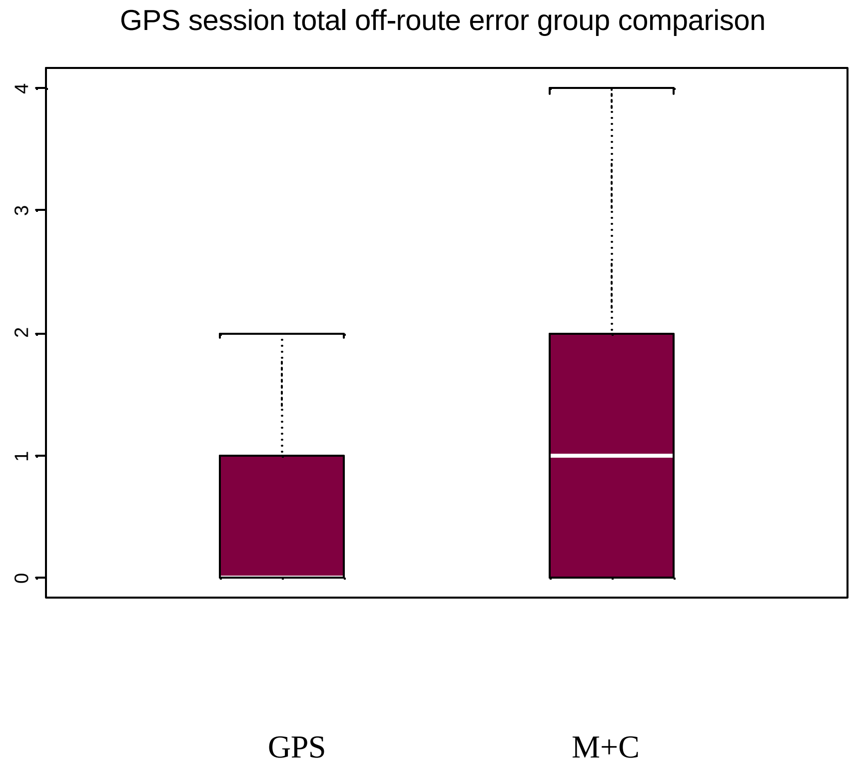



Figure 5.5 GPS Session Total Off-Route Errors Group Boxplot Comparisons for Each Checkpoint

According to the two-sample t test there is a significant difference between the group performances on the basis of checkpoint vise total off-route error. $T_{0.05,\,15}$=1.697,

t= -1.835 p= 0.038, $H_o$:$\mu_1$ - $\mu$2 =0, $H_a$:$\mu_1$ - $\mu$2 <0, $H_o$ is rejected since -1.835 < -1.697.

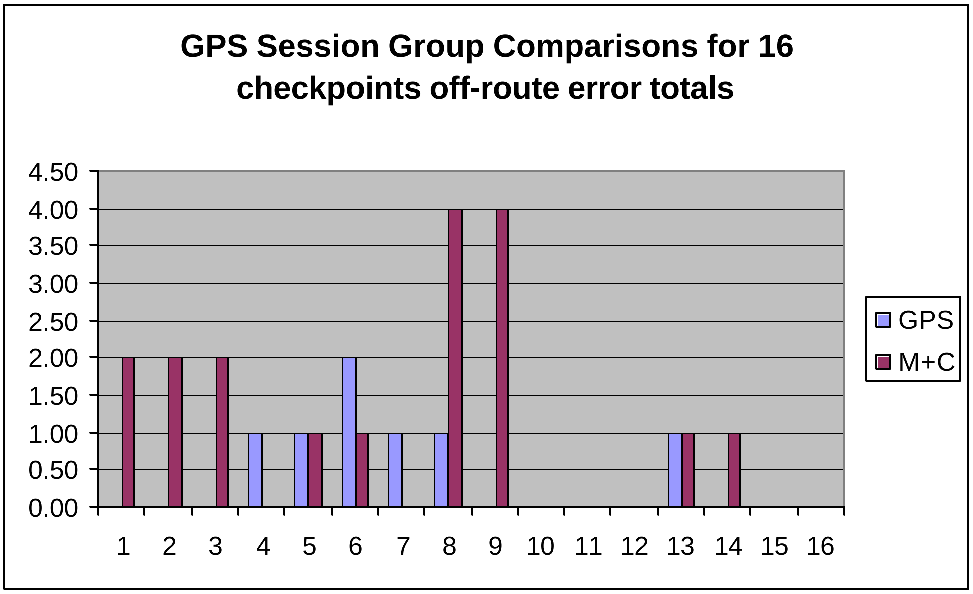



Figure 5.6 GPS Session Total Off-Route Errors Group Comparisons for each Checkpoint

A Wilcoxon Rank-Sum test did not indicate any significant difference between the group performances on the basis total off-route error means, $H_0:\mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 <0$.
$H_o$ is not rejected since Z value -1.451 is not < - 1.645. The significant difference between the groups according to the two-sample t test is not very strong since p value is close to 0.05. Also there is no significant difference between the checkpoint vice total off-route error group performances. Thus we can say that there is no significant difference between the total off-route error group performances in the GPS session.

***f. Off-route Error for Each Group Individual***

The off-route errors performed by each individual during the navigation task performed by GPS were observed and noted for both experiment groups. Monitoring any significant difference was done in the total GPS session off-route error for both group individuals. The analysis was based on the six total individual off-route errors for either group. Figure 5.7 shows the total individual off-route errors for each group.

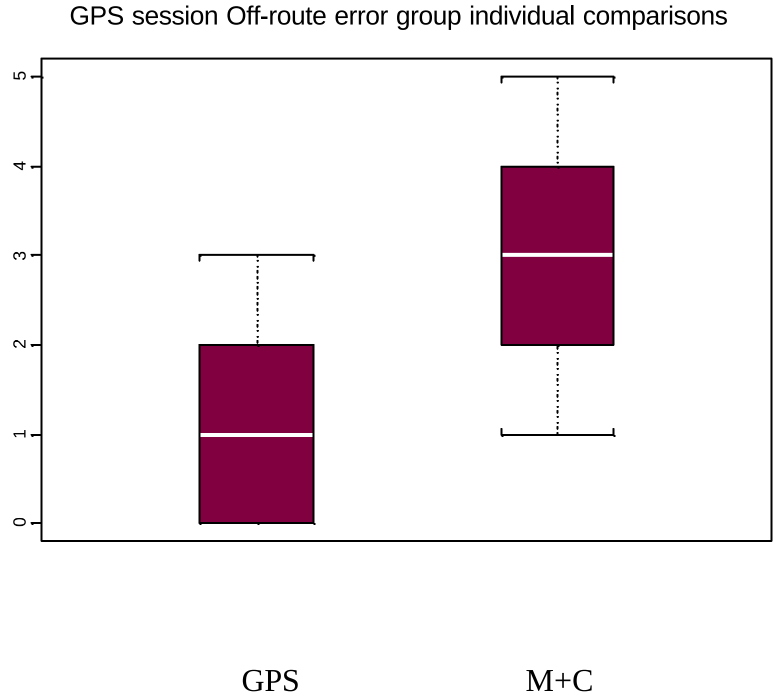



Figure 5.7 GPS Session Total Off-Route Errors Group Individual Boxplot Comparison.

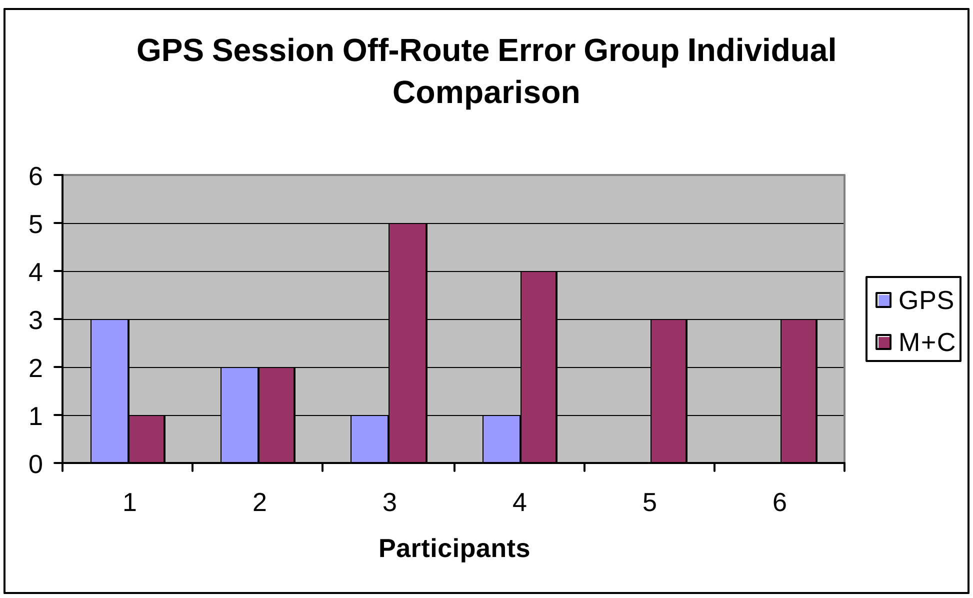



Figure 5.8 GPS Session Total Off-Route Errors Group Individual Comparison.

According to the two-sample t test there is a significant difference between the group performances on the basis of total off-route error. $T_{0.05,\ 5}$=1.812, t= -2.447 p= 0.017

$H_o$:$\mu_1 - \mu 2 = 0$, $H_a$:$\mu_1 - \mu 2 < 0$, $H_o$ is rejected since -2.477 < -1.812.

A Wilcoxon Rank-Sum test also indicated significant difference between the group performances on the basis individual total off-route error means, $H_o: \mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 < 0$. $H_o$ is rejected since Z value -1.956 < - 1.645. On the basis of total off-route error, we can say that GPS group individuals showed a better performance than the M+C group individuals in the GPS session of the experiment.

### *g. GPS Session Discussion*

According to the analyses there is no significant difference in the task completion times and off-route errors of all 16 checkpoints in the GPS session for both groups. These results are based on the analysis of the two sets of average task completion times and the total off-route error of six individuals from both groups. Having the average of data might have yielded some loss of data. This was evident when the total task completion times of six individuals from both groups were tested resulting in participants trained by the GPS method performing a better task completion time and making less off-route errors in the GPS session than the participants trained by the M+C method. Also, results indicate that although there were small differences between the data collected for each checkpoint, the total task completion data for the whole session showed significant differences for both groups. Looking at the navigation as a whole, we can say that there is a significant difference between the group performances.

### *h. GPS Session Observations*

The participants were not told about the experiment goal and the experiment sessions in detail. Thus, at the beginning participants had no idea about the two different sessions in the experiment. At the beginning of the GPS session each participant was given the GPS and instructed to find the next checkpoint.

Since the GPS group participants already expected to navigate with GPS, they began the experiment without any hesitation. The participants in this group seemed to navigate easily from one point to another. As they knew the details of GPS navigation they made few off-route errors. The GPS participants watched the direction arrow of the GPS less frequently than the M+C group only when making direction changes. Arriving at each checkpoint the GPS group participants maintain their direction choosing the new pre- recorded destination from the GPS without changing their direction. This saved some more time since the group did not have to wander around for some time until finding the correct direction. From the beginning of the session to the last checkpoint not much development occurred in the GPS group's performance. They always slowed down while approaching the checkpoints and this allowed them to stop at the exact spot.

The M+C group was trained mainly for map and compass navigation, so they expected to begin the experiment with a map and compass. Some participants asked about the use of GPS. This group also did well with the GPS, but unlike the GPS group they were somewhat hesitant. Some participants spent too much time finding the correct route although GPS had all the checkpoints previously stored. The M+C group participants always kept their eyes on the GPS direction arrow. This prevented them from getting familiar with the environment itself and decreased their attention level to the small bumps or holes in the ground as well as the tree branches. Some made too many rapid direction changes especially in the forests and fields by wandering around. Others did not slow down when approaching the checkpoints and therefore had to go back to the point.

### 2. M+C Session Results

#### *a. Task Completion Times for Each Checkpoint*

The time to complete the navigation task performed with a map and compass from one checkpoint to another was measured for both experiment groups. For this analysis the task completion times for six people in the same group are averaged for each M+C session checkpoint. The aim was to see if there was any difference in the average task completion times of all 29 checkpoints in the map +compass session for both groups. Figure 5.9 shows the task completion times by each group in the M+C session.

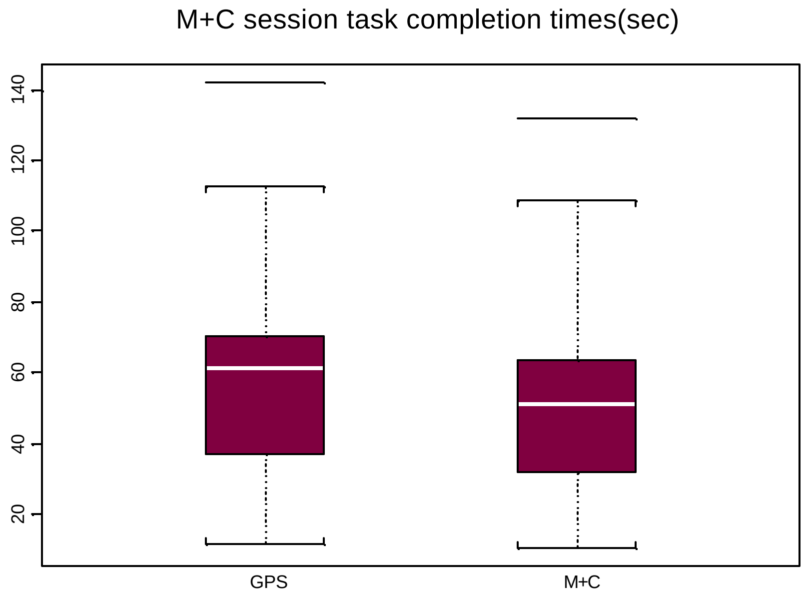



Figure 5.9 M+C Session Average Task Completion Times Group Boxplot Comparison for Each Checkpoint

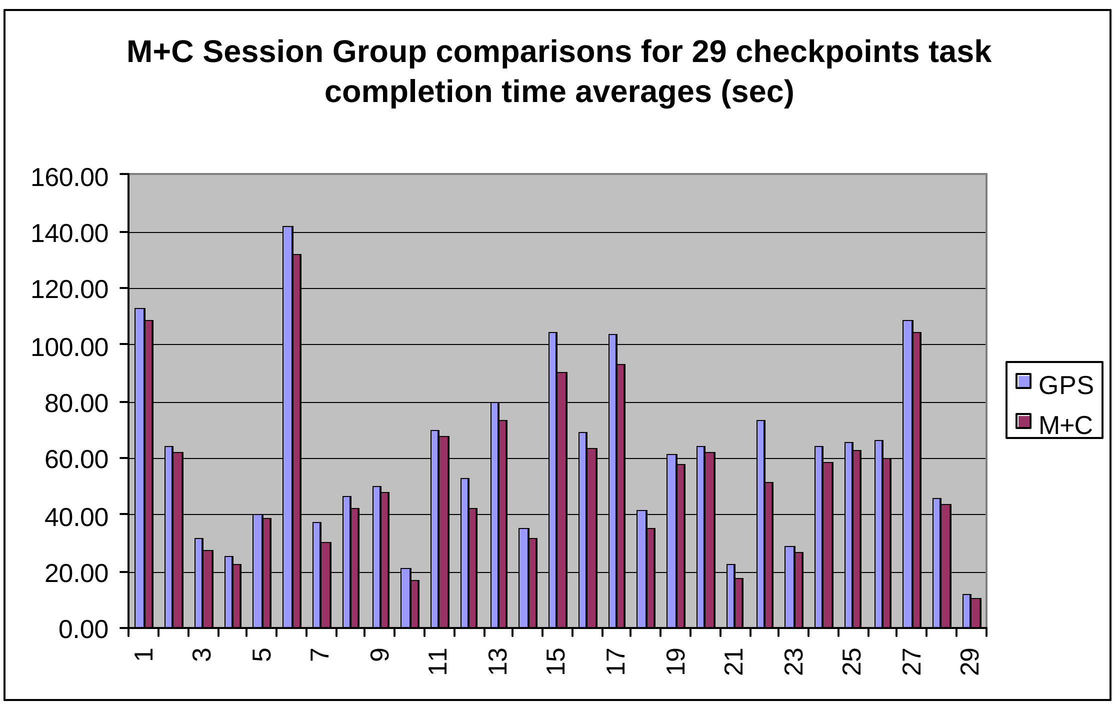



Figure 5.10 M+C Session Average Task Completion Times By Each Group for Each Checkpoint

According to the two-sample t test there is not any significant difference between the average group performances on the basis of task completion times' means. $T_{0.05, 28}=1.672$, $t= 0.683$ $p= 0.248$. $H_o:\mu_1 - \mu 2 =0$, $H_a:\mu_1 - \mu 2 >0$,

$H_o$ is not rejected since 0.683 is not > 1.672.

A Wilcoxon Rank-Sum test also failed to indicate any significant difference between the group performances on the basis of task completion times' means.

$H_o:\mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 >0$. $H_o$ is not rejected since p value 0.4039 > 0.05.

Although average M+C group task completion time was less than the average M+C group task completion time, both analyses did not yield any significance difference between groups' performances.

***b. Total Task Completion Times for Each Group Individual***

The total time to complete the navigation task performed by map and compass was measured for both experiment groups. The analysis was based on the six task completion times for each group to observe any significant difference in the total M+C session task completion times for individuals from both groups. Figure 5.11 shows the total task completion times by each group individual in the M+C session.

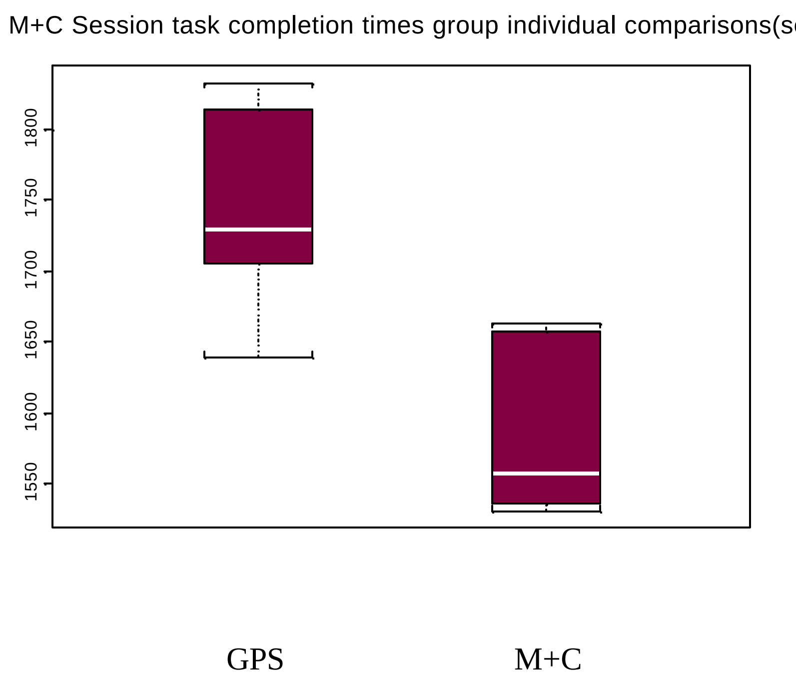



Figure 5.11 M+C Session Total Task Completion Times Group Individual Boxplot Comparison

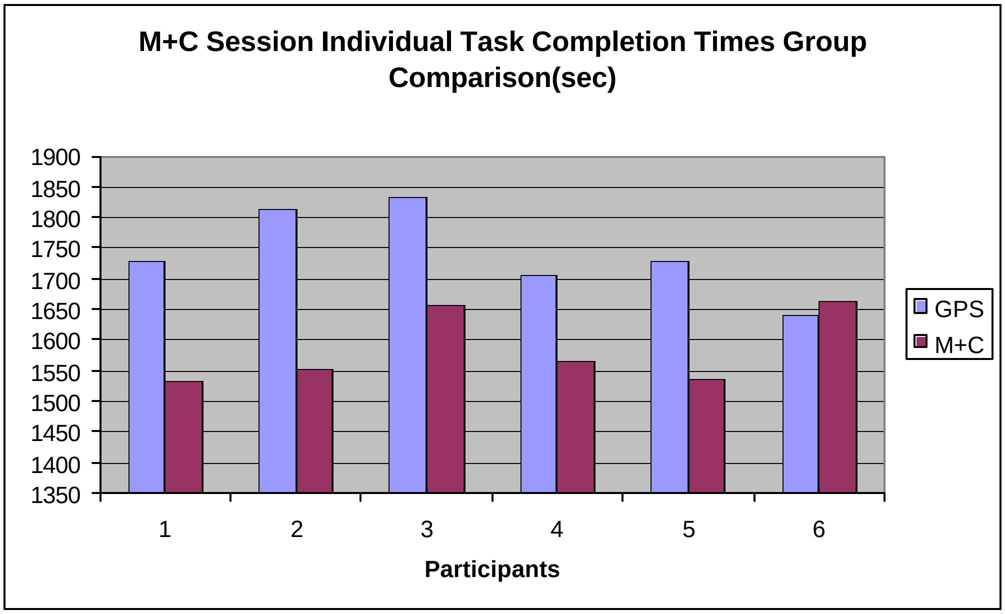



Figure 5.12 M+C Session Total Task Completion Times Group Individual Comparison

According to the t test there is a significant difference between the group performances on the basis of individual task completion times' means. $T_{0.05,5}$=1.812, t= 4.14 p= 0.0106. $H_o$:$\mu_1 - \mu 2 = 0$, $H_a$:$\mu_1 - \mu 2 > 0$, $H_o$ is rejected since 4.14 > 1.812.

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis of individual task completion times' means

$H_o$:$\mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 > 0$. $H_o$ is rejected since p value 0.0087 < 0.05.

On the basis of total task completion times we can say that the M+C group individuals showed a better performance than the GPS group individuals in the M+C session of the experiment.

***c. Distance Error for Each Checkpoint***

The distance errors seen during the M+C navigation task from one checkpoint to another were measured for both experiment groups. The aim was to observe any difference in the distance errors of all 29 checkpoints in the map +compass session for both groups. For this analysis, the distance errors for six people in the same group are averaged for each M+C session checkpoint. Figure 5.13 shows the distance errors by each group in M+C session.

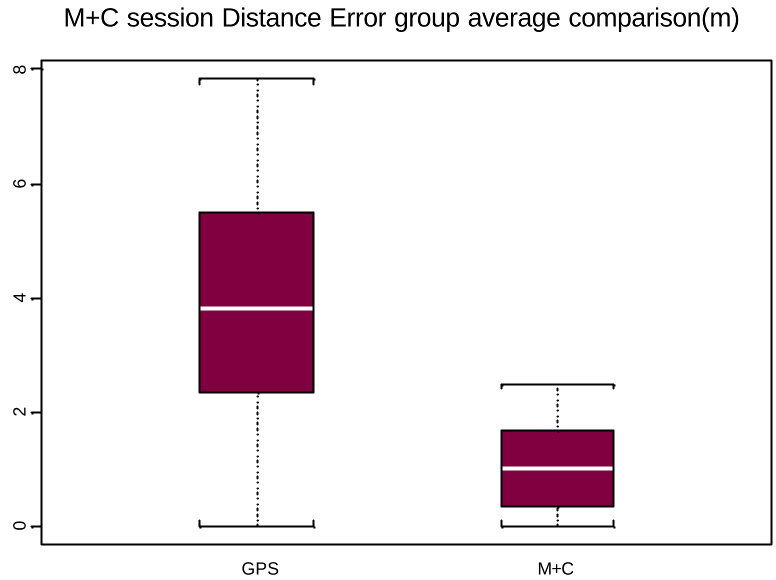



Figure 5.13 M+C Session Average Distance Error Group Boxplot Comparison for Each Checkpoint

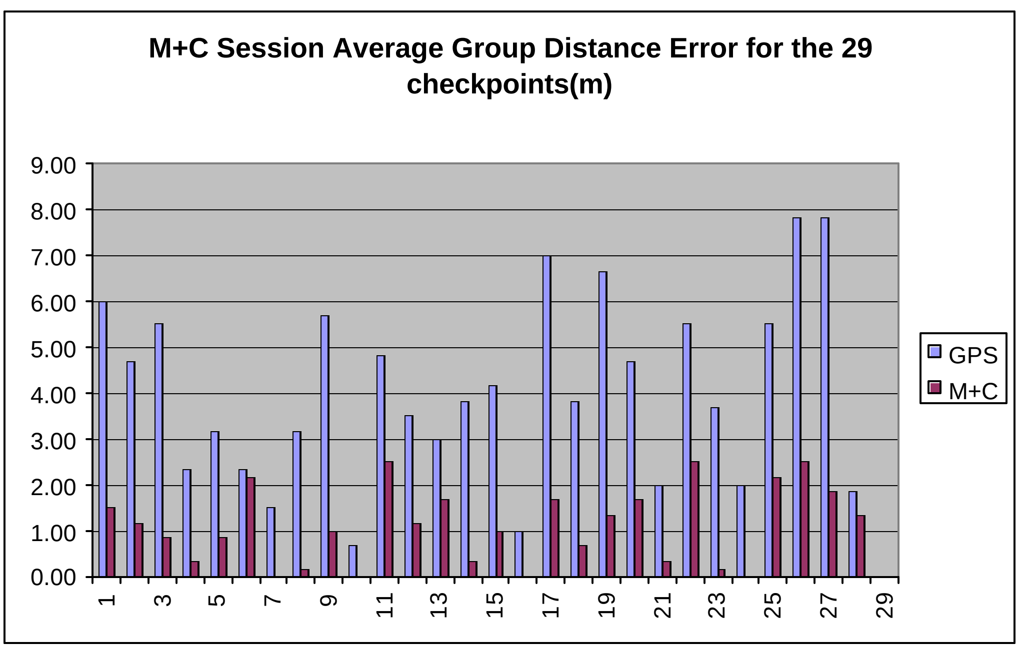



Figure 5.14 M+C Session Average Distance Error By Each Group for Each Checkpoint

According to the two-sample t test there is a significant difference between the group distance error averages. $T_{0.05,\,28}$=1.672, t= 6.79 p= 3.84E-09

$H_o$:$\mu_1$ - $\mu$2 =0, $H_a$:$\mu_1$ - $\mu$2 >0, $H_o$ is rejected since 6.79 > 1.672.

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis average distance error means, $H_o$:$\mu_1$ - $\mu$2=0, Ha: $\mu_1 - \mu_2 > 0$.

$H_o$ is rejected since Z value 5.1218 > 1.645.

On the basis of checkpoint vise average distance error we can say that the M+C group showed a better performance than the GPS group in the M+C session of the experiment.

***d. Distance Error for Each Group Individual***

The distance errors performed by each individual during the navigation task performed with a M+C were observed and noted for both experiment groups. Each group was expected to error less in the session for which they were mainly trained. Monitoring any significant difference in the M+C session average distance was done for both groups. The analysis was based on the six total individual distance errors for either group. Figure 5.15 shows the average distance errors for both groups in the M+C session.

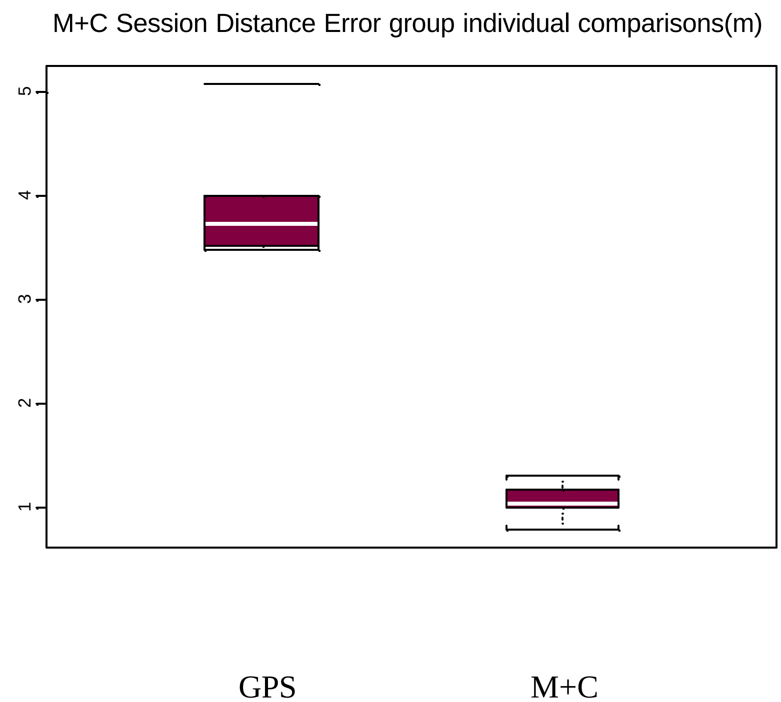



Figure 5.15 M+C Session Average Distance Error Group Individual Boxplot Comparison

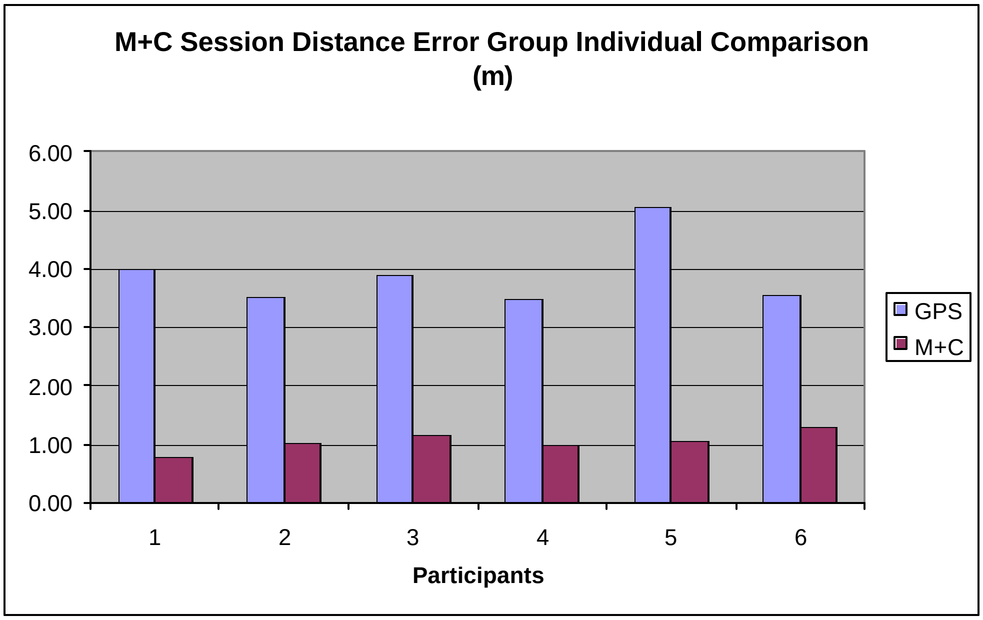



Figure 5.16 M+C Session Average Distance Error Group Individual Comparison

According to the two-sample t test there is a significant difference between the group performances on the basis of individual distance error means. $T_{0.05,\,5}$=1.812, t= 11.15 p= 2.895E-07, $H_o$:$\mu_1 - \mu 2$ =0, $H_a$:$\mu_1 - \mu 2$ >0, $H_o$ is rejected since 11.15 > 1.812.

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis average distance error means, $H_o$:$\mu_1 - \mu 2$=0, Ha: $\mu_1 - \mu_2 > 0$.

$H_o$ is rejected since p value 0.0022 < 0.05.

On the basis of individual average distance error for the whole M+C session, we can say that the M+C group performed better than the GPS group.

***e. Off-Route Error for Each Checkpoint***

The off-route errors performed by each individual during the navigation task with a map and compass were observed and noted for both experiment groups. Each group was expected to error less in the session from which they were mainly trained. Any significant difference in the M+C session total off-route errors was monitored for both groups. The analysis was based on the 29 total off-route errors for either group. Figure 5.17 shows the total off-route errors for both groups in GPS session.

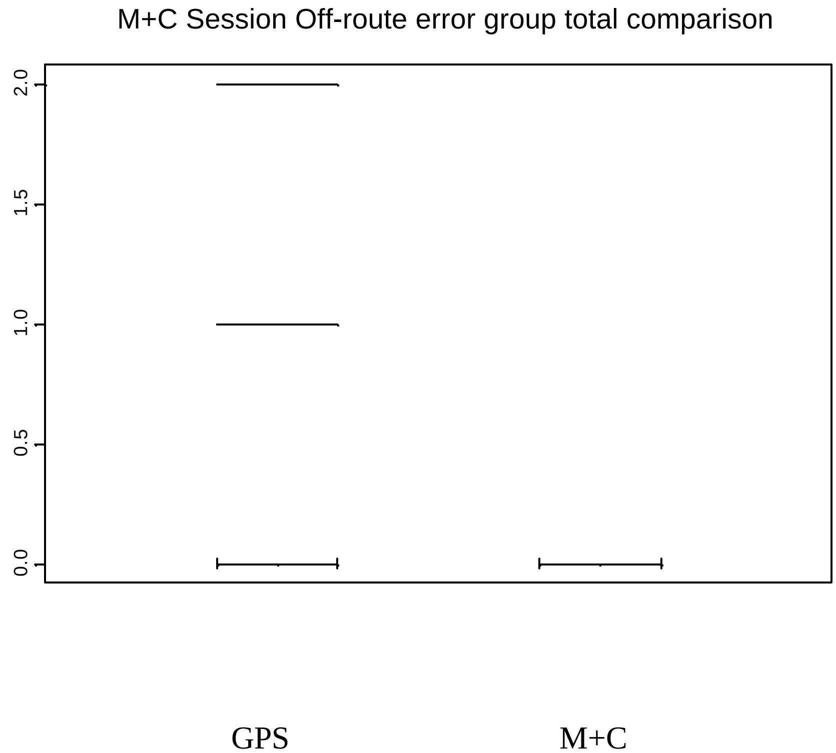



Figure 5.17 M+C Session Average Off-Route Error Group Boxplot Comparison for Each Checkpoint

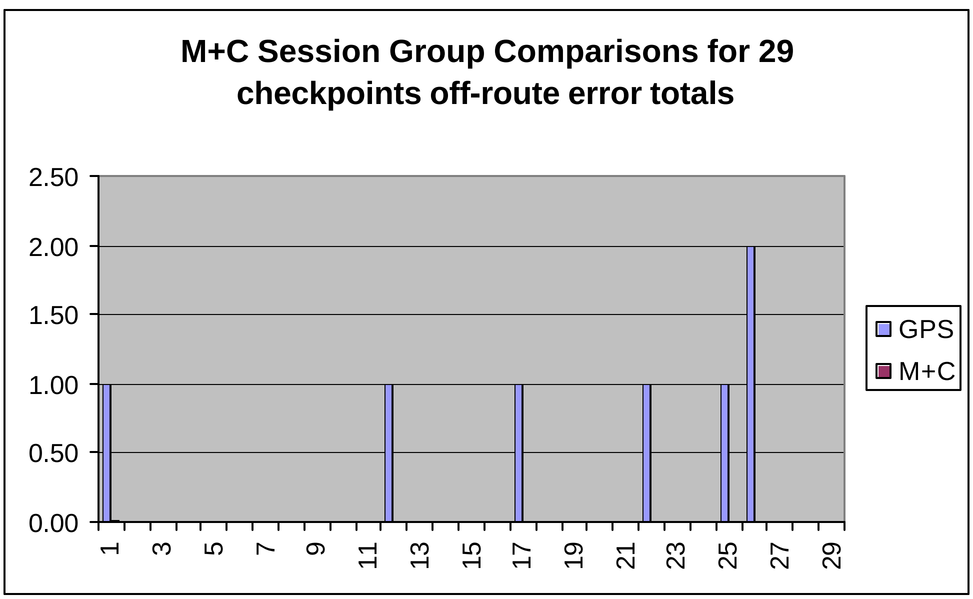



Figure 5.18 M+C Session Average Distance Error Group for Each Checkpoint

According to the t test there is a significant difference between the group off-route error averages. $T_{0.05, 28}$=1.672, t= 2.540 p= 0.0069, $H_o$:$\mu_1$ - $\mu$2 =0, $H_a$:$\mu_1$ - $\mu$2 >0. $H_o$ is rejected since 2.540 > 1.672.

A Wilcoxon Rank-Sum test also indicated a significant difference between the group performances on the basis total off-route error means

$H_o$:$\mu_1$ - $\mu$2=0, Ha: $\mu_1 - \mu_2 > 0$. $H_o$ is rejected since z value 2.0632 > 1.645.

On the basis of checkpoint vise total off-route error, we can say that the M+C group performed better than the GPS group in the M+C session of the experiment.

### *f. Off-Route Error for Each Group Individual*

The off-route errors performed by each individual during the navigation task performed by GPS were observed and noted for both experiment groups. Any significant difference in the total GPS session off-route error was observed for both group individuals. The analysis was based on the six total individual off-route errors for each group for the whole M+C session. Figure 5.19 shows the total individual off-route errors for each group.

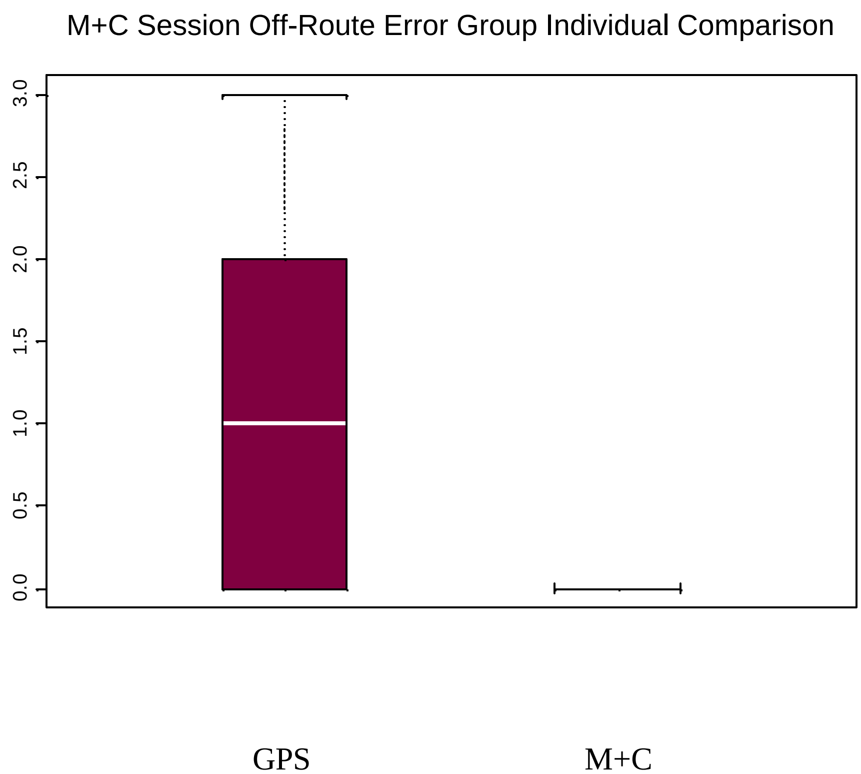



Figure 5.19 GPS Session Total Off-Route Errors Group Individual Boxplot Comparison.

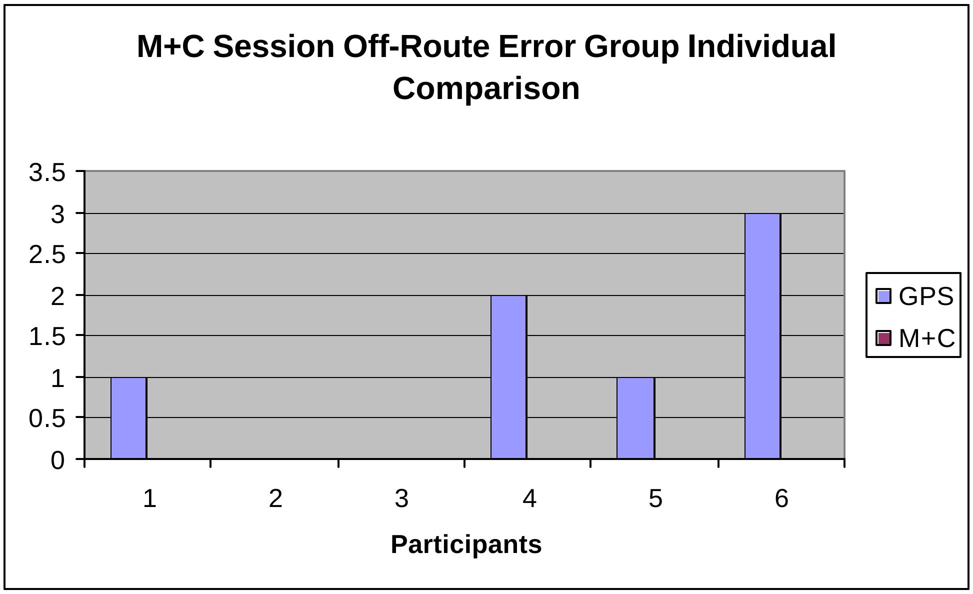



Figure 5.20 GPS Session Total Off-Route Errors Group Individual Comparison.

According to the t test there is a significant difference between the groups' performances on the basis of individual total off-route error. $T_{0.05,5}$=1.812, t= 2.444 p= 0.017

$H_o$:$\mu_1$ - $\mu 2$ =0, $H_a$:$\mu_1$ - $\mu 2$ >0, $H_o$ is rejected since 2.444 > 1.812.

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis individual total off-route error means

$H_o$:$\mu_1$ - $\mu 2$=0, Ha: $\mu_1$ - $\mu_2$ > 0. $H_o$ is rejected since z value 2.1966 > 1.645.

On the basis of individual off-route error we can say that M+C group performed better than the GPS group in the M+C session of the experiment. The M+C group made no off-route errors in this session.

### *g. M+C Session Discussion*

According to the analyses there is no significant difference in the task completion times of all 29 checkpoints in the M+C session for both groups. These results are based on the analysis of the two sets of average task completion times of six individuals from both groups. Having the average of data might have yielded some loss of data. This was evident when the total task completion times of six individuals from both groups were tested resulting in participants trained by M+C method performing a better task completion time in the M+C session than the participants trained by the GPS method. Unlike the GPS session, the small differences between the distance error and off-route error data collected from each checkpoint were also significant. The M+C group performed the task at each checkpoint during the total M+C session with less distance error and less off-route error. We can say that there is a significant difference between the group performances on the basis of task completion times, distance error, and off-route error.

#### *h. M+C Session Observations*

The M+C session started at the fifth main checkpoint. This part of the experiment had 29 total checkpoints. The participants were asked to put away the GPS and complete the rest of the experiment with a map and compass. The M+C group was observed easily adapting to the map, compass and the distance-azimuth chart. The GPS group participants appeared anxious and hesitated in abandoning the GPS. Some of this group ended up getting lost without the GPS. Initially they had difficulty orientating to the compass with the map. Some GPS group participants forgot to count their paces because they had been accustomed to navigating with the GPS. The M+C group checked the map more than the GPS group. Some GPS group participants navigated only by using the distance-azimuth chart and the compass, so they were not as certain about locating the checkpoints as the M+C group participants were. Checking the map allowed viewing the terrain features including the paths, heights, and vegetation. Terrain features helped the participants correct themselves. Without the map, navigation was simply based on dead reckoning. The feeling of going off-route or getting lost forced the GPS group to go through the forest area, but the map + compass group usually preferred going around the forest by making 90 degree left and right turns.

### 3. Group Comparisons

#### *a. GPS Group in GPS Session - M+C Group in M+C Session Individual Normalized Average Task Completion Times Comparison*

The task completion times for each session were normalized to minimize the negative effect of an unequal number of checkpoints and unequal distances between checkpoints. Then the average task completion time was calculated for each group' participants in his/her trained navigation task. This analysis was performed in order to check any difference between the performance levels of groups when they navigated in their main sessions. This means that the comparison was done between GPS group in GPS session, and the M+C group in M+C session. Figure 5.21 shows the normalized individual average task completion times for each group in their main session.

GPS Group in GPS Session - M+C Group in M+C Session Individual Normalized
Average Task Completion Times Comparison

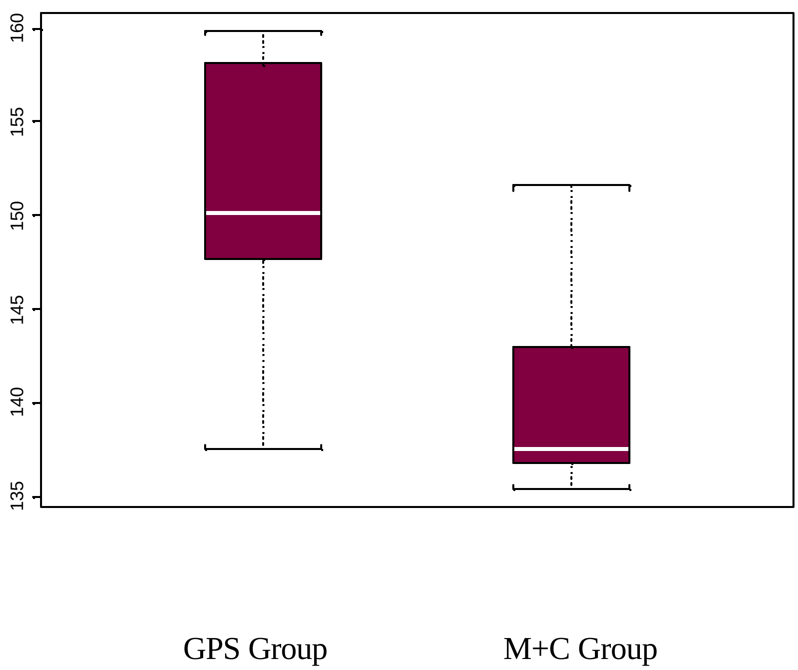



Figure 5.21 GPS Group in GPS Session - M+C Group in M+C Session Individual Normalized Average Task Completion Times Boxplot Comparison

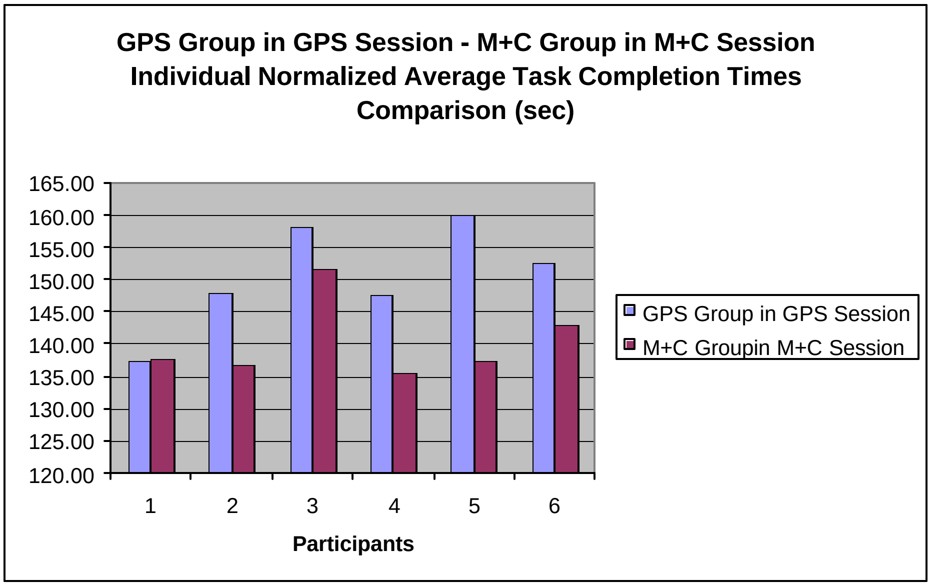



Figure 5.22 GPS Group in GPS Session - M+C Group in M+C Session Individual Normalized Average Task Completion Times Comparison

According to the t test there is a significant difference between the groups' performances on the basis of individual task completion times' means. $T_{0.05,\ 5}$=1.812, t= 2.466 p= 0.0166, $H_o$:$\mu_1 - \mu2 = 0$, $H_a$:$\mu_1 - \mu2 > 0$, $H_o$ is rejected since 2.466 > 1.812.

A Wilcoxon Rank-Sum test also indicated significant difference between the groups' performances on the basis of individual task completion times' means

$H_o$:$\mu_1 - \mu2=0$, Ha: $\mu_1 - \mu_2 > 0$. $H_o$ is rejected since p value 0.0411 < 0.05.

As a result, we can say that the M+C group individuals showed a better performance in the M+C session than the GPS group participants in the GPS session of the experiment.

## 4. GPS Group Results

### *a. Task Completion Times for Each Session*

The time to complete the complete navigation task in each session performed by the GPS group was measured. This analysis was done in order to observe whether the GPS group performed the task in the GPS session of the experiment in a shorter time than that performed in the M+C session. The number of the checkpoints and the distances between each checkpoint differed in both sessions. To be able to perform the analysis, the time data was normalized for both sessions and the average task completion times for both sessions was calculated. The analysis was done on the normalized time data averages of the GPS group participants in 2 sessions. Figure 5.21 shows the GPS group normalized task completion times comparison for 2 sessions.

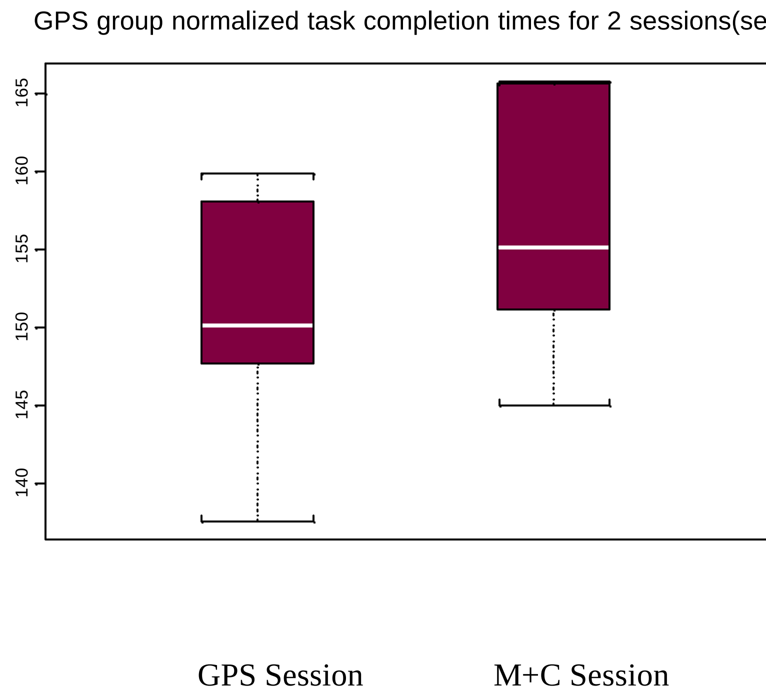



Figure 5.23 GPS Group Normalized Task Completion Times Boxplot Comparison for 2 Sessions

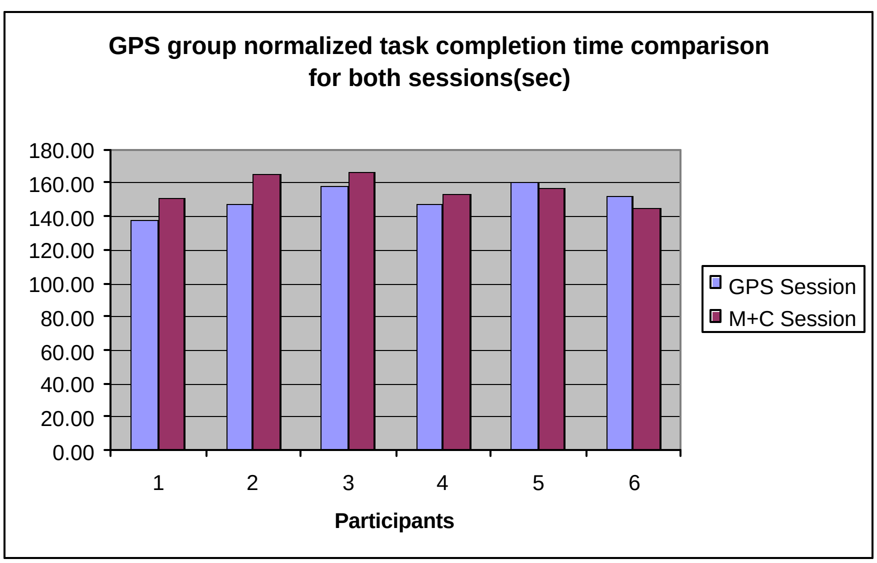



Figure 5.24 GPS Group Individual Normalized Task Completion Times Comparison for 2 Sessions

According to the paired t test there is no significant difference between the group performances on the basis of individual task completion times' means. $T_{0.05,5}$=2.015,

t= -1.483 p= 0.099. $H_o$:$\mu_1 - \mu2 = 0$, $H_a$:$\mu_1 - \mu2 < 0$, $H_o$ is not rejected since -1.48 > -2.01.

A Wilcoxon Rank-Sum test also failed to indicate any significant difference between the groups' performances on the basis normalized individual task completion times' means $H_o$:$\mu_1 - \mu2=0$, Ha: $\mu_1 - \mu_2 < 0$. $H_o$ is not rejected since p value 0.2188 > 0.05. Although average GPS session task completion time is less than the average M+C session task completion time, neither analyses yielded any significance performance difference between the two sessions.

***b. Distance Error for Each Session***

In the GPS session of the experiment there was no distance error observed because the participants could see the exact location of the checkpoint from the GPS. Thus, no comparative analysis was performed. Therefore, we concluded that the GPS as a navigation aid helps to prevent distance errors.

***c. Off-Route Error for Each Session***

The total off-route errors done by the GPS group individuals in each session was observed. This analysis was done in order to see if the GPS group made less off-route errors in the GPS session of the experiment than in the M+C session. Figure 5.23 shows the GPS group off-route error comparison for the two sessions.

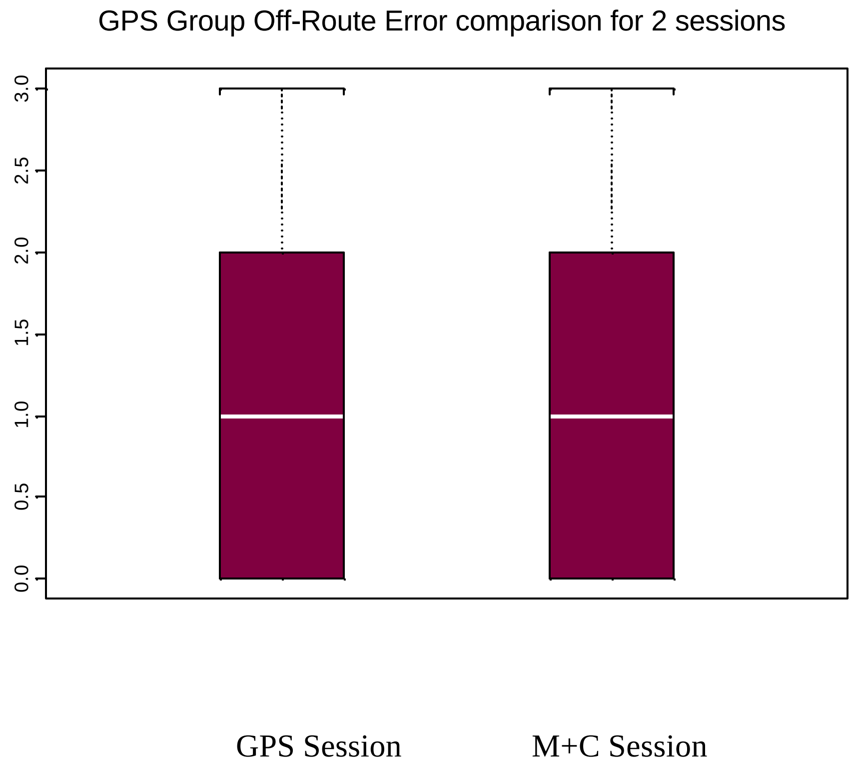


Figure 5.25 GPS Group Off-Route Error Boxplot Comparison for 2 Sessions

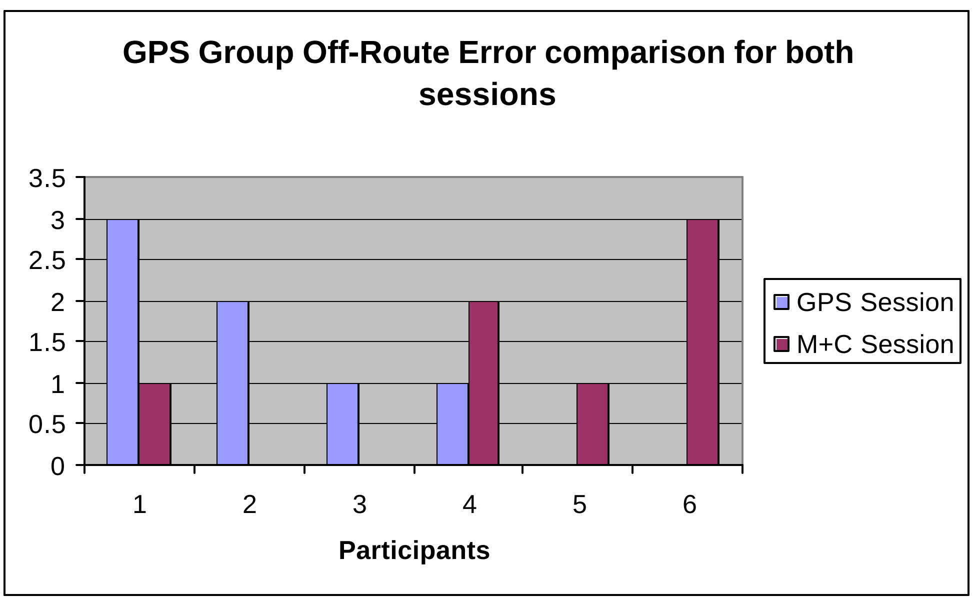


Figure 5.26 GPS Group Off-Route Error Comparison for 2 Sessions

According to the paired t test there is no significant difference between the group performances on the basis of total individual off-route error. $T_{0.05,\ 5}$=2.015, t= 0.0 p= 0.5 $H_o$:$\mu_1 - \mu 2$ =0, $H_a$:$\mu_1 - \mu 2 < 0$, $H_o$ is not rejected since 0.0 > -2.015.

A Wilcoxon Rank-Sum test also failed to indicate any significant difference between the groups' performances on the basis normalized individual task completion times' means $H_o$:$\mu_1 - \mu 2$=0, Ha: $\mu_1 - \mu_2 < 0$. $H_o$ is not rejected since z value 0 < 1.645.

Neither analyses yielded any significance performance difference between the two sessions. The GPS group performed in the M+C session as they did in the GPS session in terms of off-route errors.

### 4. M+C Group Results

#### *a. Task Completion Times for Each Session*

The time to complete the entire navigation task in each session performed by the M+C group was measured. This analysis was done in order to see if the M+C group performed the task in the M+C session of the experiment in a shorter time than that performed in the GPS session. The number of the checkpoints and the distances between each checkpoint differed in both sessions. To be able to perform the analysis, the time data was normalized for both sessions and the average task completion times for both sessions are calculated. The analysis was done on the normalized time data averages of the M+C group participants in 2 sessions. Figure 5.25 shows the M+C group normalized task completion times comparison for the two sessions.

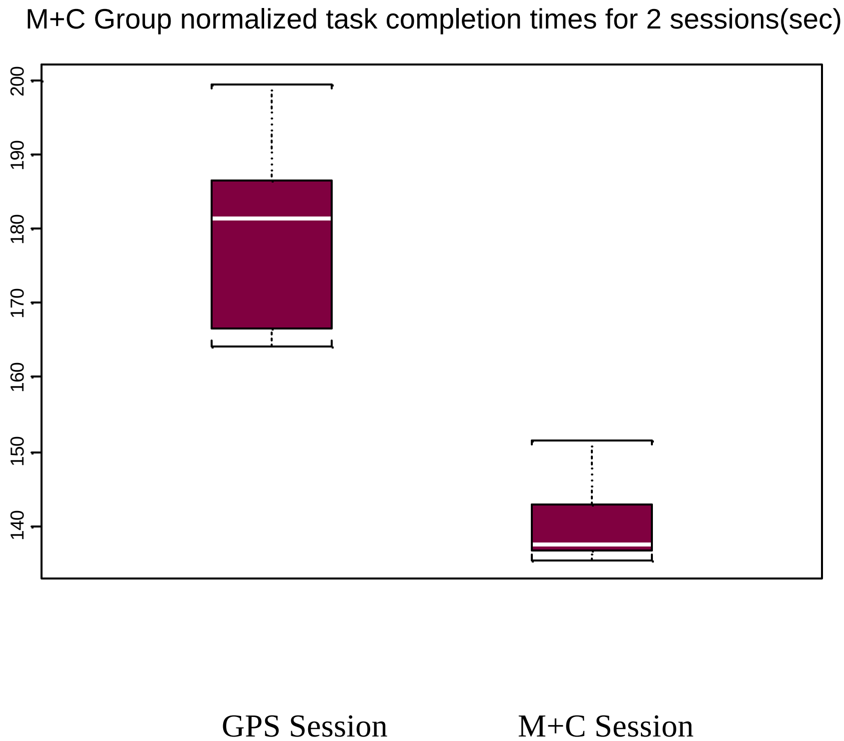



Figure 5.27 M+C Group Normalized Task Completion Times Boxplot Comparison for 2 Sessions

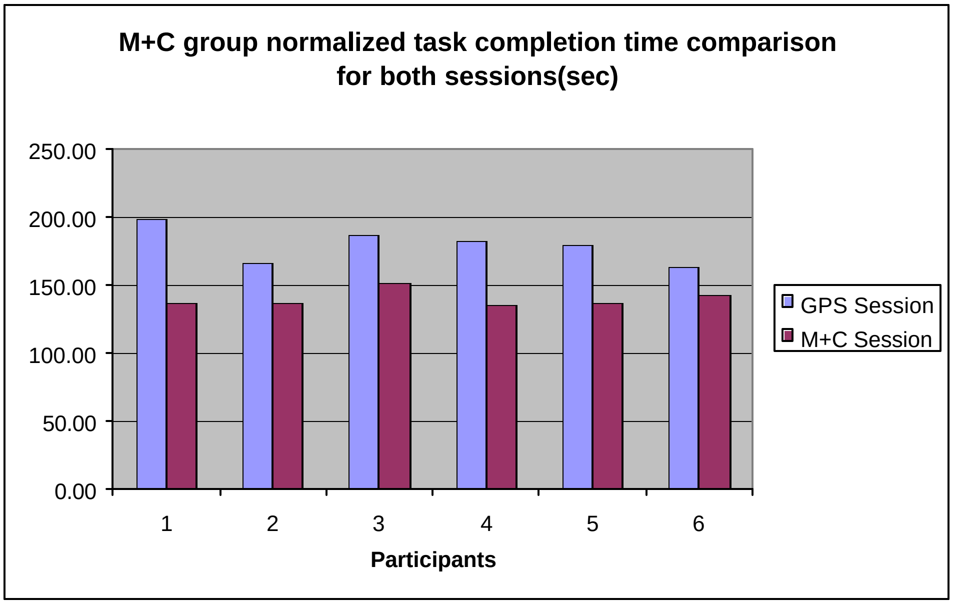



Figure 5.28 M+C Group Normalized Task Completion Times Comparison for 2 Sessions

According to the paired t test there is a significant difference between the group performances on the basis of task completion times' means. $T_{0.05,\ 5}$=2.015, t= 6.79 p= 0.00053. $H_o$:$\mu_1 - \mu 2 = 0$, $H_a$:$\mu_1 - \mu 2 > 0$, $H_o$ is rejected since 6.79 > 2.015.

A Wilcoxon Rank-Sum test also indicated a significant difference between the groups' performances on the basis normalized individual task completion times' means

$H_o$:$\mu_1 - \mu 2=0$, Ha: $\mu_1 - \mu_2 > 0$. $H_o$ is rejected since p value 0.0312 < 0.05.

Both analyses indicated a significance performance difference between the two sessions in terms of task completion times. The M+C group performed the M+C session tasks in less time than they did in the GPS session, which means a better performance.

***b. Distance Error for Each Session***

In the GPS session of the experiment there was no distance error observed because the participants could see the exact location of the checkpoint from the GPS. Thus, no comparative analysis was performed. Conclusively, GPS as a navigation aid helps to prevent distance errors.

***c. Off-Route Error for Each Session***

The total off-route errors done by the M+C group individuals in each session was observed. This analysis was done in order to observe whether the M+C group made more off-route errors in GPS session of the experiment than they did in the M+C session. The M+C group made no off-route errors in the M+C session. Figure 5.27 shows the M+C group off-route error comparison for two sessions.

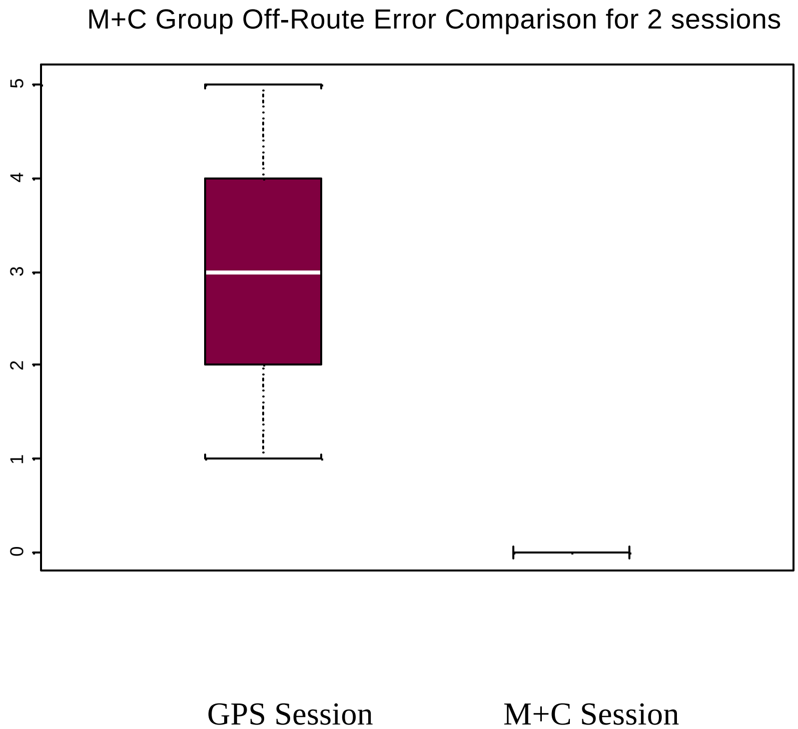



Figure 5.29 M+C Group Off-Route Error Boxplot Comparison for 2 Sessions

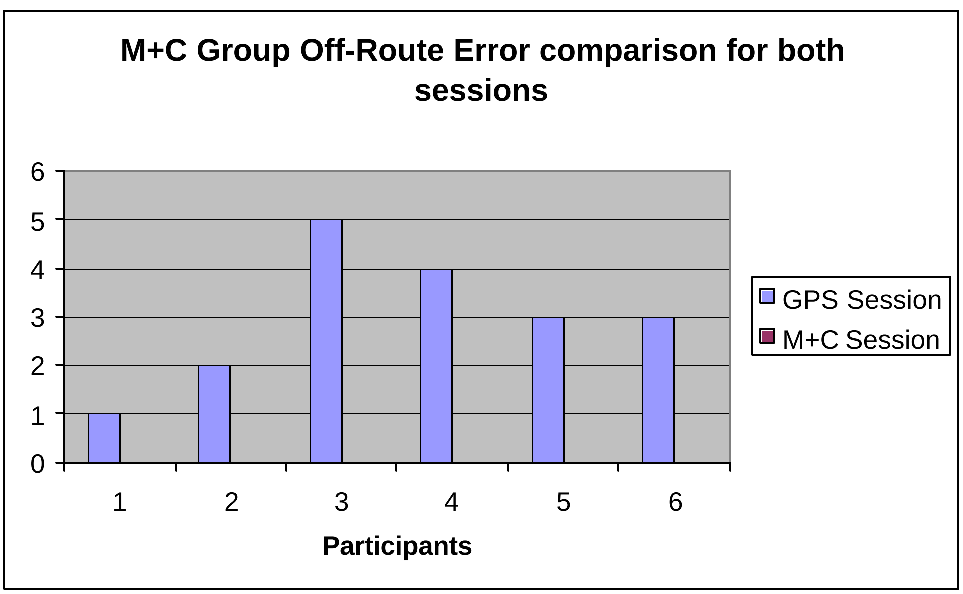



Figure 5.30 M+C Group Individual Off-Route Error Comparison for 2 Sessions

According to the paired t test there is a significant difference between the group performances on the basis of individual off-route error means. $T_{0.05,5}$=2.015, t= 5.196 p= 0.0017. $H_o$:$\mu_1 - \mu2 = 0$, $H_a$:$\mu_1 - \mu2 > 0$, $H_o$ is rejected.

A Wilcoxon Rank-Sum test also indicated a significant difference between the groups' performances on the basis individual off-route error means. $H_o$:$\mu_1 - \mu2=0$, Ha: $\mu_1 - \mu_2 > 0$. $H_o$ is rejected since z value 2.1024 > 1.645.

As seen from the graphs the M+C group made no off-route errors in the M+C session. In addition both analyses indicated a significance difference between the two sessions meaning that M+C group did better in the M+C session in terms of off-route error.

### 5. Ability Classification Results

#### *a. GPS Group Results*

An ability classification was made among the individuals before the experiment groups were arranged. This analysis in Figure 5.31 identifies a regression between the ability classification and the group performances. The first analysis was done between the GPS session task completion times and the ability classification grades. The second analysis was done between the M+C session task completion times and the ability classification grades.

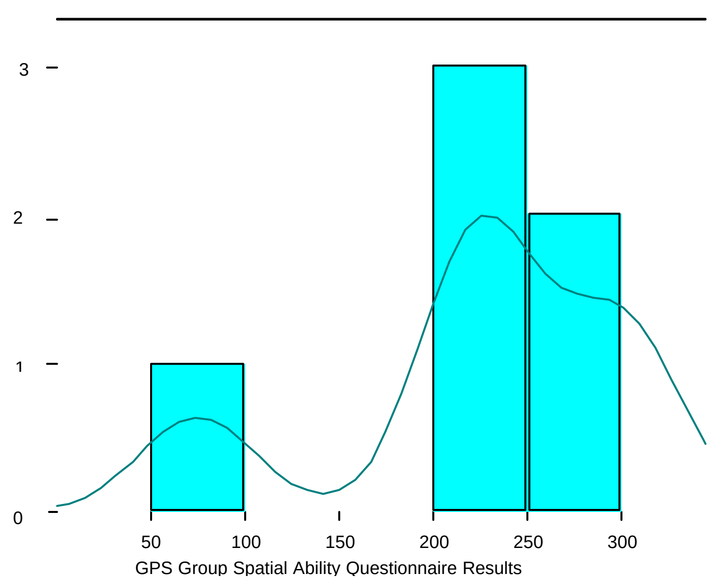



Figure 5.31 GPS Group Individuals Spatial Ability Questionnaire Grades Histogram

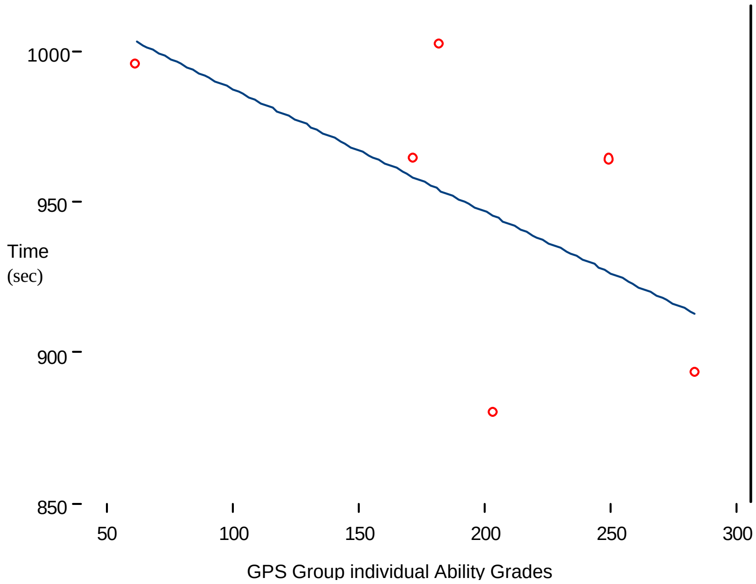



Figure 5.32 GPS Group Spatial Ability ~ GPS Session Task Completion Times Graph

Although the above graph indicates that the task completion times are somewhat less in the better grades, according to the regression analysis there is no significant regression between the ability grades and the GPS session task completion times with $\alpha=0.05$ significance level. Since P value is 0.203 > 0.05, the null hypothesis Ho:$\beta=0$ is not rejected in the favor of Ha: $\beta\neq0$.

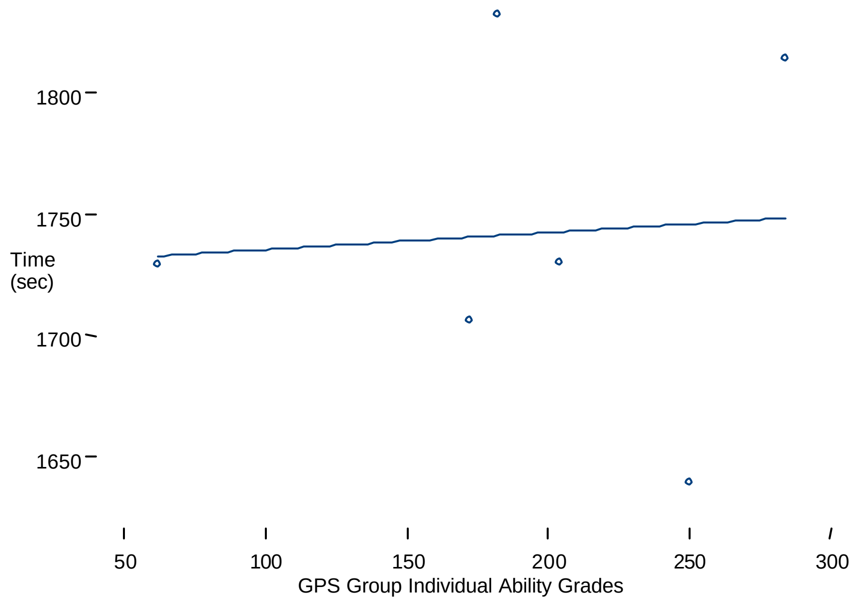



Figure 5.33 GPS Group Spatial Ability ~ M+C Session Task Completion Times Graph

According to regression analysis there is no significant regression between the GPS groups' spatial ability grades and the M+C session task completion times with $\alpha$=0.05 significance level. Since P value is 0.887 > 0.05, the null hypothesis. Ho:$\beta$=0 is not rejected in the favor of Ha: $\beta \neq 0$.

### *b. M+C Group Results*

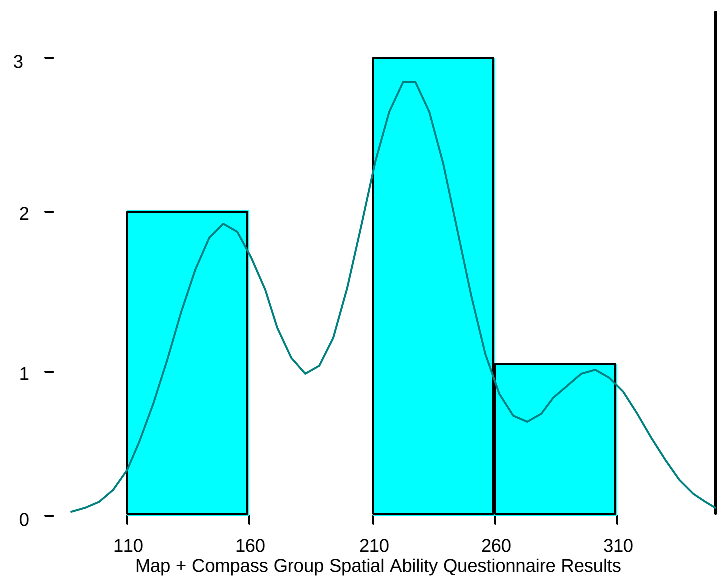



Figure 5.34 M+C Group Individuals Spatial Ability Questionnaire Grades Histogram

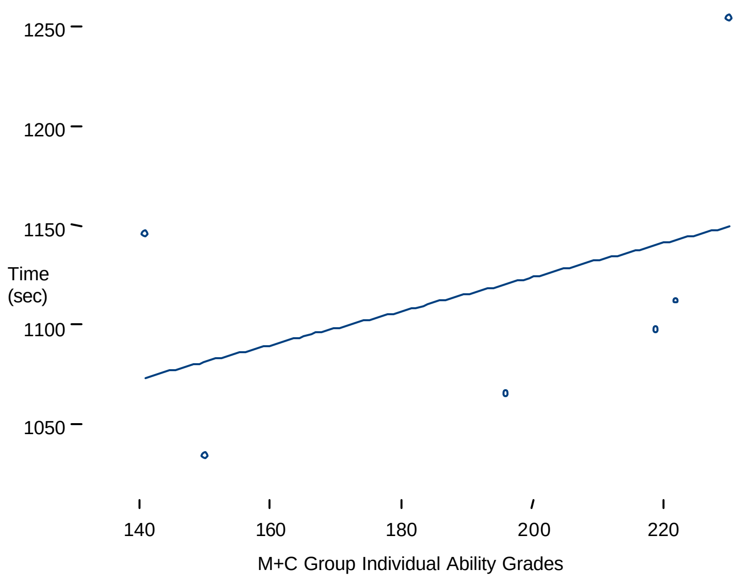



Figure 5.35 M+C Group Spatial Ability ~ GPS Session Task Completion Times Graph

According to the regression analysis there is no significant regression between the M+C group is spatial ability grades and the GPS session task completion times with $\alpha$=0.05 significance level. Since P value is 0.397 > 0.05, the null hypothesis. Ho:$\beta$=0 is not rejected in the favor of Ha: $\beta \neq 0$.

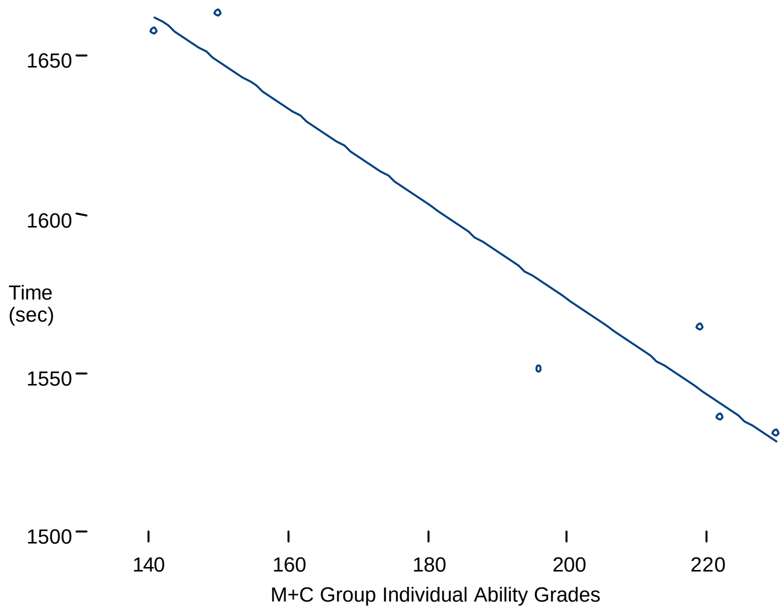



Figure 5.36 M+C Group Spatial Ability ~ M+C Session Task Completion Times Graph

Figure 5.36 indicates that the better scores in the ability questionnaire yielded better task completion times in the M+C session for the M+C group's individuals. According to the regression analysis there is a significant regression between the M+C group's spatial ability grades and the M+C session task completion times with $\alpha$=0.05 significance level. Since P value is 0.00245 < 0.05, the null hypothesis Ho:$\beta$=0 is rejected in the favor of Ha: $\beta \neq 0$.

The regression coefficients are $\beta_0$ = 1163.2, $\beta_1$ = -0.61256, and the regression equation is$Y_i$= 1163.2 –0.61256 * $X_i$ . To write the above equation more clearly, M+C Group Spatial Ability Grade = 1163.2 –0.61256 * (M+C Session Task Completion Time).

# VI. CONCLUSIONS AND FUTURE WORK

## A. CONCLUSIONS

This thesis experiment studied the effects of navigation aids and the transfer of training on human error in different land navigation tasks. The participants of two different training groups performed land navigation tasks in the same environment with different checkpoints and with two different navigation methods. The performance levels were assessed through several analyses. The navigating behavior of the participants was observed to compare the navigation methods. The results of the experiment were then analyzed in order to determine if a significant difference exists between the methods and the groups. The following conclusions were drawn from both the qualitative and quantitative results previously presented:

1. Participants trained by the Map and Compass method performed better in the map + compass session than participants trained by the GPS method performed in the GPS session. This indicates that when land navigators have all navigation aids available, those trained with the map and compass navigate better than the GPS trained navigators. We can assume that any person will use the navigation aid that is most familiar. Thus, the map-compass native land navigators will prefer the map and compass, while the GPS native land navigators prefer GPS. If the map-compass native land navigators perform better than the GPS native land navigators when all the navigation aids are available, the likelihood of navigating problems is apparent for the GPS native land navigators when GPS is not available.
2. Participants trained by the GPS method performed better in task completion time and made less off-route errors in the GPS session than the participants trained by the M+C method. This indicates that GPS training can be positively transferred to the real environment. Additionally, although GPS is an easy navigation aid to use, training is still required for better performance.

3. Participants trained by the M+C method performed better in task completion time, made less off-route errors, and less distance errors in the M+C session than the participants trained by the GPS method. This indicates that M+C training can be positively transferred to the real environment. The results indicated that M+C training is strongly required for this kind of navigation.
4. No distance errors could be recorded in the GPS session for either group. This indicates that GPS is a very helpful navigation aid which is highly accurate in identifying the exact locations while reducing human error.
5. Alternatively, when navigating by GPS, individuals' trust level in the GPS is too high. Those using GPS navigate predominantly on GPS suggesting that a GPS signal originating from satellites or jamming devices can be very effective.
6. Although the performance levels of the individuals in the GPS group decreased somewhat in the M+C session, the results did not indicate any significant difference between the performance levels of the GPS group in each session. This could be attributed to the positive effect of using a distance and azimuth chart, which makes the M+C navigation simpler.
7. The individuals in the M+C group performed much better in the M+C session than in the GPS session. This indicates that M+C training is positively transferred to the real environment.
8. The performance differences between the groups in the GPS session are less than the performance differences between the groups in the M+C session. This indicates that GPS is a simple, user friendly navigation aid while the map and compass is not that simple. Training is always required for this kind of navigation. People accustomed to GPS navigation may have difficulty adapting to map and compass navigation when they have to switch from GPS to map and compass navigation.
9. There is a positive regression between the spatial ability level and the map-compass navigation performance level of the map-compass group.

There is no regression between the GPS navigation performance levels and the spatial ability levels of either group. This indicates that spatial ability is not strongly required for GPS navigation. Anybody can navigate using the GPS with very little training. Spatial ability is strongly required for map and compass navigation.

10. Navigating with a navigation aid that the individual is not used to caused some human errors. This effect was especially obvious when the GPS group navigated with the map and compass.
11. An individual, especially a military person, who has to navigate would have more experience in both navigating methods and, therefore, be able to switch the devices easily.

## B. FUTURE WORK

While this thesis validated the performance differences between the navigation methods and the effects of different navigation aids training methods on navigation, human error, and the transfer of training, there remain significant areas for future work and exploration. This section focuses on some possible future enhancements and modifications to the experiment presented in this thesis.

### 1. Navigating in Virtual Environments

This experiment can be repeated in virtual environments and the effects of navigation aids can be tested in natural environment simulations without causing the participants any level of fatigue. Also more participants can be tested because of less time required for the actual testing phase, which will provide more data. Weather conditions will not be an issue.

### 2. Experiment with Actual Military Personnel

The experiment can be designed in a larger area and without the training due to using professional military navigators. These participants can be tested with GPS against jamming devices and under low light level conditions. This could produce very interesting results.

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# APPENDIX A. EXPERIMENT OUTLINE

1) In Brief/Consent Form

    a) Time – 5 min
    b) Location – Fort Ord Military Area
    c) OIC – Ltjg Omer T. Arisut
    d) Materials – Consent Form, Privacy Act Statement, Minimal Risk Consent Form, pencil, In Briefing Script

2) Ability Classification/UC Santa Barbara spatial knowledge and ability" questionnaire.

    a) Time – 15 min
    b) Location – Fort Ord Military Area
    c) OIC – Ltjg Omer T. Arisut
    d) Materials – UC Santa Barbara spatial knowledge and ability" questionnaire form, pencil.

3) Navigation Methods and Navigation Aids Familiarization.

    a) Time – 1 Hr.
    b) Location – Fort Ord Military Area
    c) OIC – Ltjg Omer T. Arisut
    d) Materials – "Map, Compass, and GPS familiarization" notes, 1:5000 scale Fort Ord Map, military compass, Garmin hand GPS, familiarization test sheet, pencil.

4) Training

    a) Time – 1 Hr.
    b) Location – Fort Ord Military Area
    c) OIC – Ltjg Omer T. Arisut
    d) Materials –1:5000 scale Fort Ord Map, military compass, Garmin hand GPS, stopwatch, azimuth and distance chart, hat, note sheet, pencil.

5) Experiment

    a) Time – 1 Hr.
    b) Location – Fort Ord Military Area
    c) OIC – Ltjg Omer T. Arisut
    d) Materials –1:5000 scale Fort Ord Map, military compass, Garmin hand GPS, stopwatch, azimuth and distance chart, visual wooden made checkpoint signs, hat, data collection sheet, pencil.

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# APPENDIX B. IN BRIEFING

Welcome to Fort Ord Military Area. My name is Omer T. Arisut. I'm a Ltjg in Turkish Navy. Thank you for participating in this experiment. This experiment deals with the effects of training differences in navigation and human error related to it.

This experiment does not test your intelligence or physical performance level this type of an environment, but it tests your navigation abilities, and transfer of training performance related to spatial knowledge. Your performance will be used for only research purposes, and it will not be used in any type of personal records. Prior to starting the experiment you will be asked to read and sign a series of consent forms. Please read them carefully and ask me if you have any questions. The experiment will take approximately 3 hours including the familiarization and training sessions. If you don't have any question, please read and sign the consent forms.

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# APPENDIX C. CONSENT FORMS

## 1. GENERAL

The forms in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. This appendix consists of three documents: Consent Form, Minimal Risk Consent Statement, and the Privacy Act Statement. Each participant is required to read and sign these documents before he is allowed to participate in the study.

## 2. CONSENT FORM

**PARTICIPANT CONSENT FORM**

1. **Introduction.** You are invited to participate in a study that requires land navigation to find the pre-determined and fixed checkpoints using the map, compass, and GPS as navigation aids. With information gathered from you and other participants we hope to discover insight on how does training affect the usage of map, compass, and GPS as a result of training transfer and the effects of navigation aids on human error. You'll navigate using the navigation aids to find the checkpoints in Ford Ord Military Area after an hour of training. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.

2. **Background Information.** Data is being collected by the Naval Postgraduate Moves Department for use to develop navigation techniques both for military purposes and virtual environments.

3. **Procedures.** If you agree to participate in this study, the researcher will explain all required tasks in detail. There will be a familiarization, a training and an experiment session. In the familiarization session you will be familiarized with land navigation basics and using navigation aids In the training session you will navigate with the either map and compass or GPS and learn more about navigation. In the experiment session you'll be expected to find the checkpoints using the navigation aids. Running is not required. The total amount of time is approximately 3 hours.

4. **Risks and Benefits.** Because this research involves minimal risks to individuals with getting hurt by poisonous oak found in the area, and has discomforts like getting tired, we request that IF YOU CONSIDER YOURSELF AS SUCH, PLEASE INFORM THE EXPERIMENT ADMINISTRATOR AT ONCE, and NOT PROCEED ANY FURTHER. The benefits to the participants will be to contribute to current research in developing navigation techniques, learning navigation basics and learning how to navigate and having a real navigation experience.

5. **Compensation.** Cold beverages, water, and chocolate will be given as reward. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, Dr. Rudolph P. Darken (831) 656-4072 darken@nps.navy.mil.

9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

-------------------------------------------- --------------------------

Participant's Signature Date

-------------------------------------------- --------------------------

Researcher's Signature Date

### 3. MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: Effects Of Navigation Aids On Human Error In A Complex Navigation Task.

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary, refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Professor Rudy Darken, Principal Investigator, and about my rights as a research participant or concerning a research related injury is the Modeling Virtual Environments and Simulation Chairman. A full and responsive discussion of the elements of this project and my consent has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

Signature of Principal Investigator Date Signature of Volunteer Date

Signature of Witness Date

## 4. PRIVACY ACT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: DETERMINE SOUND SYSTEM COMPLEXITY AND ITS EFFECT ON THE USER'S SENSE OF PRESENCE IN A VIRTUAL ENVIRONMENT

3. Use: Physiological response data will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. The Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act may grant use of the information to legitimate non-government agencies or individuals.

4. Disclosure/Confidentiality:

a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number, which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which are not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____________________________________________________________________________

Signature of Volunteer Name, Grade/Rank (if applicable) DOB SSN Date

____________________________________

Signature of Witness Date

# APPENDIX D. SPATIAL ABILITY QUESTIONNAIRE

## 1. GENERAL

The forms in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. This appendix consists of Santa Barbara Sense-of-direction-scale. Each participant is required to answer these questions in order to be placed in an experiment group.

## 2. SANTA BARBARA SENSE-OF-DIRECTION SCALE

Participant ID: Date: Sex: Age:

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experience. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle “1” if you strongly agree that the statement applies to you, and “7” if you strongly disagree, or some number in between if your agreement is intermediate. Circle “4” if you neither agree nor disagree.

1. I am very good at directions.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My “sense of direction” is very good

Strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W)

Strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble in understanding directions.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good mental map of my environment.

Strongly agree 1 2 3 4 5 6 7 strongly disagree

# APPENDIX E. FAMILIARIZATION NOTES

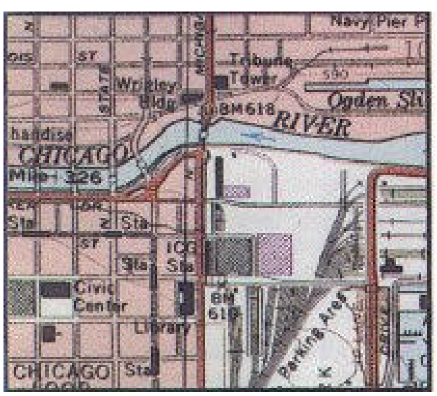
## 1. GENERAL

The notes in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. This appendix consists of the notes prepared to familiarize the participants with simple map, compass, and GPS knowledge and navigating tips, and the test questions related to these notes. Each participant is given these notes and then tested for what he/she learned.

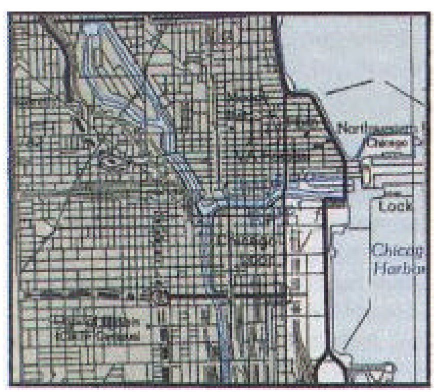
## 2. FAMILIARIZATION NOTES

### The Map – A Simplified View

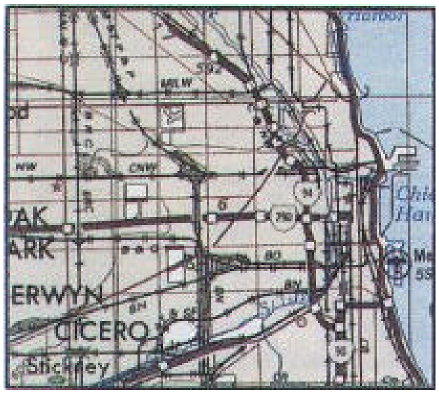
A map is a simplified view of the surface of the earth seen from above and greatly reduced in size. Exactly how much of the map is reduced in size is indicated by the scale that is always given on a map. Maps vary in quality. Some are schematic and generalized, while others are very exact and full of detail. Below are four maps of the same area but differing in scale. The scale the land area shown has been reduced 24000,100000, 250000, 500000 times in the below maps respectively.



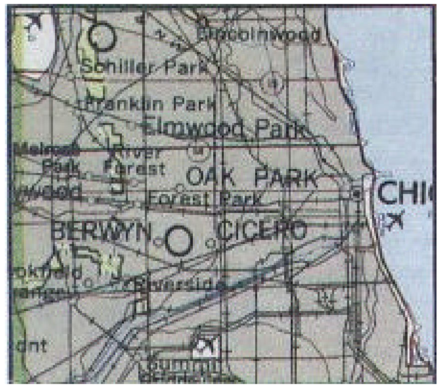

1:24,000




1:100,000




1:250,000




1:500,000

Scale 1:10 000 means that the land has been reduced 10 000 times on the map. Everything is 10 000 times smaller.

**1:10 ~~000~~**

A simple rule of thumb: Take away the last three digits of the scale, as in the example above, and then 1 millimeter on the map is translated into 10 meters on the ground.

There are maps for all sorts of uses from leisure activities to specialized maps for the military, for meteorologists, surveyors or geologists. A good rule for looking at a new map is to first look at the legend, which explains the symbols and indicates the scale. The most common map scale is 1:25 000.

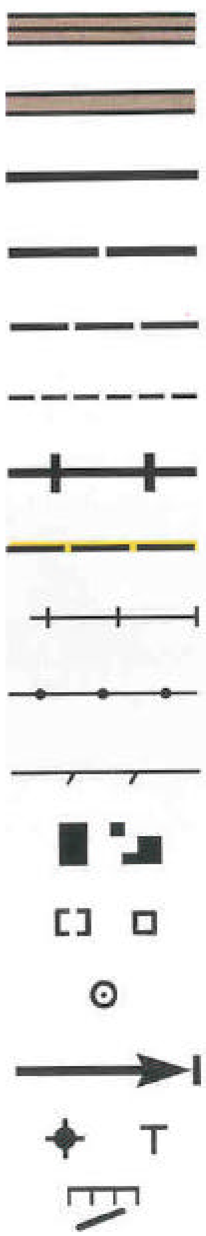
The following colors apply to orienteering maps. Six or seven colors are normally used.

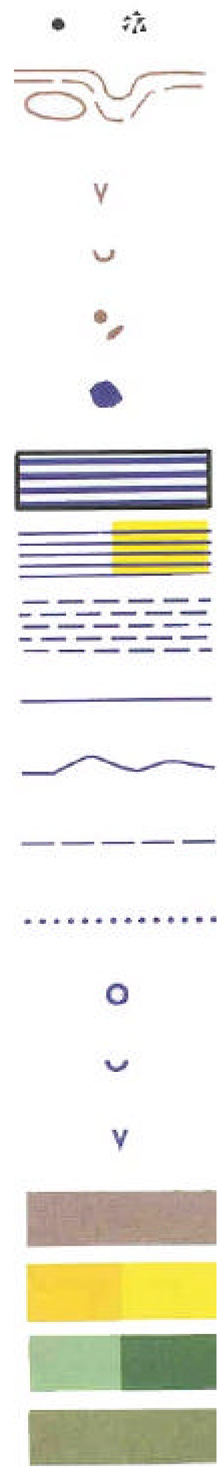
- The WHITE areas denote runable forest.
- Anything BROWN has to do with difference of altitude: mountains, heights, ravines, and hollows.
- Everything YELLOW represents open land: fields, meadows or forest clearings.
- GREEN indicates dense, impenetrable forest; the darker the color, the more impenetrable it is.
- YELLOW/GREEN indicates land that is built on, for example gardens and lawns.
- BLUE areas and features are to do with water.
- BLACK is the most color used, and indicates numerous things such as roads, paths, power lines, buildings, rocks, and precipices.

Other kinds of maps use different color keys. Note that military and orienteering maps use different color schemes.

# Symbols

Symbols on the map are drawn in different colors. Below is the list of the most common symbols and their colors.

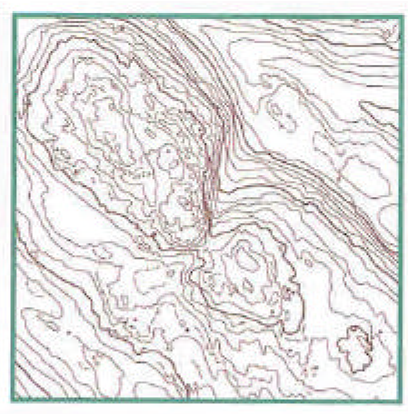




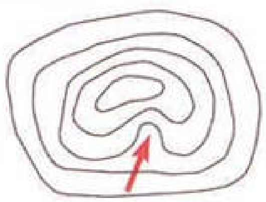
| | |
|---|---|
| Motorway | Boulder, Boulder field |
| Major Road | Contour Lines |
| Road | Pit |
| Minor Road | Small Depression |
| Vehicle Track | Spot Height |
| Small Path | Lake/open water |
| Railway | Uncrossable march |
| Illuminated Path | Marsh, open marsh |
| Power Line | Indistinct marsh |
| Stone Wall | Crossable small watercourse |
| Fence | Crossable watercourse |
| Buildings | Minor Water channel |
| Ruin | Narrow marsh |
| Cairn | Well |
| Firing Range | Spring |
| High Tower, Small Tower | Waterhole |
| Cliff/Rock Face | Asphalt/paved area |
| | Open Land |
| | Dense vegetation |
| | Settlement |

## Contour Lines

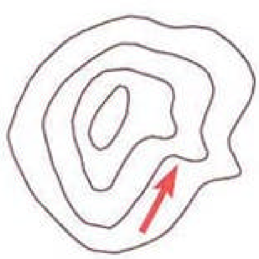
Contour lines give very important information about differences in elevation. They also indicate where there are precipices, valleys and peaks as well as how steep the terrain is.



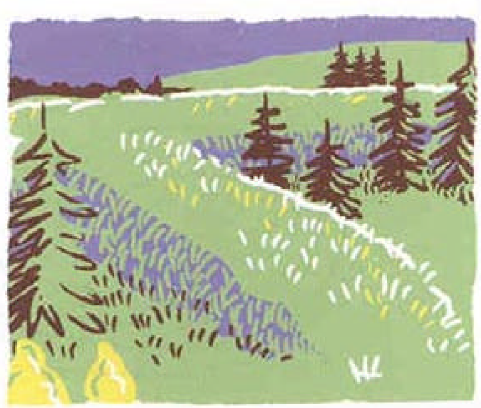
The difference in height between the contours on an orienteering map is normally five meters. But just as the scale can differ between different maps the interval between contours also differ. The key or legend, to the map usually indicates the height between the contour lines. The more contours there are, the higher the hill. When the contours are close together, the ground is steep and when they are spread at, the slope is gentle.

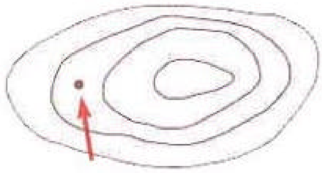


*If one or more contours goes "inwards", this indicates a hollow, that is a ravine, re-entrant or gully.*

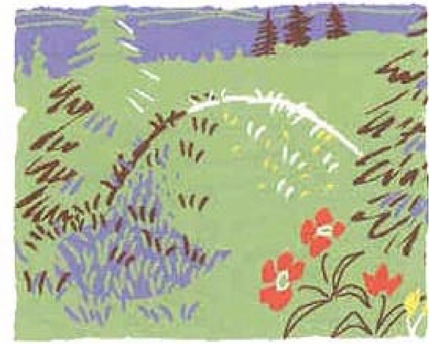


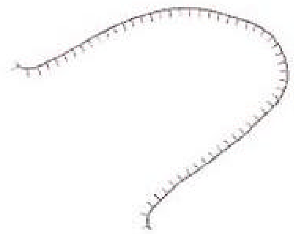
*If one or more contours goes "outwards", this shows a spur or ledge that sticks out.*





*A brown dot shows a little hill (or knoll), the size of which does not affect the contour above it, or the one below it. It may be only 1–2 metres high.*





*A brown contour with "ticks" indicates a gravel pit.*

*A brown "v" or "u" means a small pit (1–2 metres in diameter).*

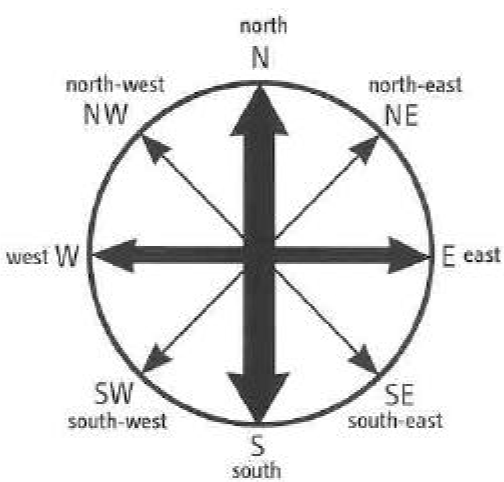
*Contours that meet and are shown with short lines (ticks) pointing inwards mean a hollow/depression, or a deeper pit.*

## The Use of the Map

To use the map, in other words to read it, requires one essential action: the map has to be oriented. The map can be compared with a piece of jigsaw puzzle. The piece can only be fitted into the puzzle in one way. The same is true for maps. They only fit the terrain in one way. It is usually easiest to orientate the map when you see a large and conspicuous objects or features such as buildings, roads or a lake. The map can be oriented using a compass, or by aligning it to the features on the ground.

## Elements of a Compass

All hand-held compasses have one thing in common – the magnetic needle or card. The colored part, most often red, always points north, providing there are no objects made of iron, magnets or other compasses in the immediate vicinity.




North, south, east, and west are called the cardinal points. North-east, south-east etc. are called the inner-cardinal points.

What is it that makes a compass needle consistently point in a north south direction? The answer is the powerful but invisible force known as magnetism. The earth is like a giant magnet.

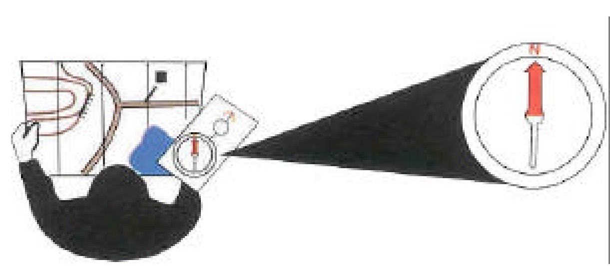
## Magnetic Variation (Declination)

Magnetic north, to which the needle points, is not exactly at the North Pole as defined by the meridians. Variation arises because the magnetic and geographical north poles do not coincide.

**Golden rules**: Store and use your compass well away from any magnetic field.
Check that your compass functions correctly before you leave home and in time to rectify any problems you may find.

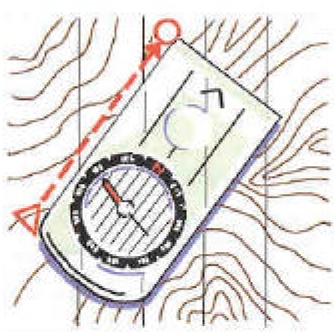
## Orientation With a Compass

When the magnetic meridians are parallel with the compass needle the map is oriented. The north-seeking end of the needle must be to the north of end of the meridian.

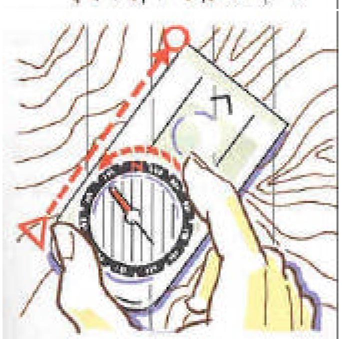


Your compass will help you to:

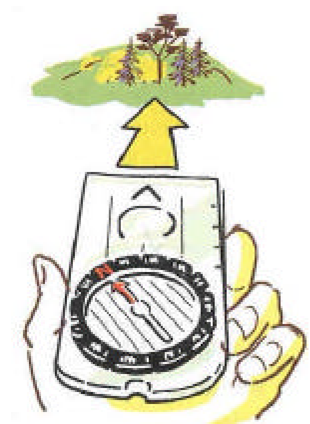
- Orientate the map
- Move in particular directions



Place the compass on the map with one edge in line with where you are and pointing in the direction where you want to go.



Turn the compass so that N on the housing points north on the map. You can also make use of the north south lines in the bottom of the housing. These should be parallel with the meridians on the map with red lines pointing north and black lines pointing south.



Remove the compass from the map and hold it horizontally in front of you. Turn your body so that the colored (red) part of the needle is pointing to "N" on the compass housing.

Now move in the direction that the "direction of travel" arrow shows on the baseplate.

It is a lot easier to accurately point a compass with a long baseplate. When you have found out in which direction you should be moving, look for a feature on the ground. This can be an individual tree or other well defined feature. When you reach the feature you look for another feature and continue in this way until you reach your destination.

## Magnetic Variation

Magnetic variation is the difference in degrees, between true north and magnetic north. When the magnetic variation is west, the difference must be ADDED when working from grid (meridian) to magnetic bearings and SUBTRACTED when the magnetic variation is east. The reverse applies when working from magnetic bearings to grid.

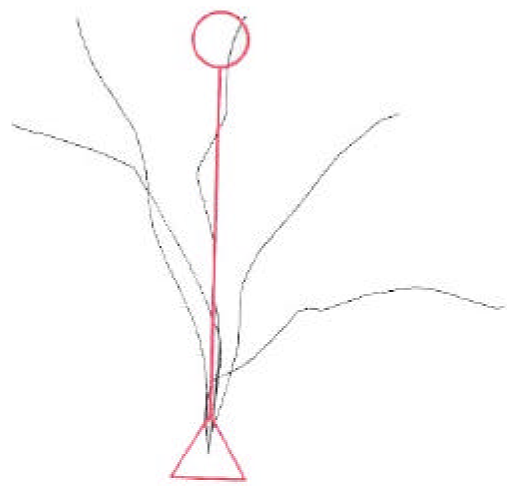
A common mistake for the compass is to be held too low and close to the waist. The problem then, is that the line of sight must be accurately raised through a comparatively long arc, in the direction of bearing being taken. The answer is to hold the compass as high as possible and out ahead of you, while still being able to see that the needle is parallel to the orientation lines in the bottom of the capsule.

Iron ore deposits, high-voltage power lines and iron objects influence the compass needle.

## Sometimes things go wrong

In a hurry one can make a mistake when taking a bearing. A common error is placing the "N" of the compass to the south instead of the north on the map. You then move in exactly the opposite direction to the one intended. Another common error is not looking at the compass often enough when you have decided on your direction. There is then a risk that you travel to the left or right of your intended direction of travel, when following a compass bearing.

In an experiment five people were to move 500 meters in a given direction without a compass. At the start they were able to get their bearings from a compass that had been set. After that they were to follow the bearing as carefully as possible without a compass. The results of their movements are shown in the figure.



## GPS

The Global Positioning System (GPS) is a satellite based system that allows us to establish very rapidly exactly where we are anywhere in the world. The GPS consists of 24 satellites positioned above 20 000 kilometers above the earth in orbit in six different paths. Each satellite continuously emits a signal that can be picked up by GPS receivers on the ground. Certain advanced GPS receivers can also show the route to a destination in the countryside. The GPS receiver continuously updates its position and thus the current distance to and direction of the destination is shown. The great benefit that GPS has brought to navigators on foot is, of course, the fixing of their position anywhere in the world. However by a fixing position, it also establishes distance, something that no other instrument has ever been able to do.

## Pacing

Pace counting is used by orienteerers to accurately estimate relatively short distances. First you need to establish how many paces you take per 100 meters. To do this walk a known distance of 300 or 400 meters on flat ground. Count the number of paces and find the average number taken per 100 meters. It is easier to keep count when pacing, if you count every time your left or right foot strikes the ground as one.

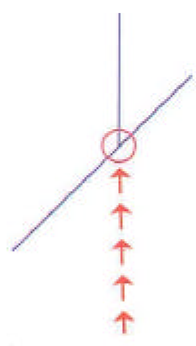
The compass bearing must be adjusted when one detours round obstacles such as bushes, hills or marshes.

## Select a route

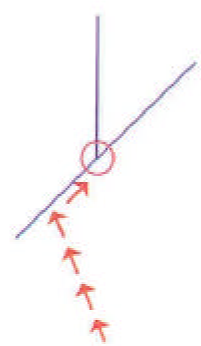
By route selection we mean the route you decide to take before moving from one place to another. The routes we are interested in do not normally include roads or tracks even though you may perhaps follow a track along part of your route. The straight route is not always the best alternative. There are often several possible routes between two places. The art of good route selection usually involves identifying the safest, sometimes quickest, and hopefully the least physically demanding route.

When you select a route, it is always easiest to follow line features. These can be roads, paths, power lines, edges of fields, stone walls, lake sides, streams and ditches.

There is always a risk that you will have to move sideways to avoid bushes or suchlike and that you will then deviate from your bearing. When you finally reach the path you don't know whether the fork is to the left or to the right.



Instead, if you take a bearing to a point to the side of the fork (aim off), you will know which way to turn when you reach the path.



## Attack point

An attack point is a feature or mapped object, which appears easy to navigate to, and from which it is easier to navigate to your final destination.

## 3. FAMILIARIZATION TEST

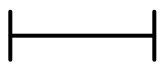
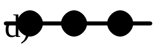
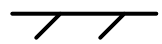
Participant name:

Date:

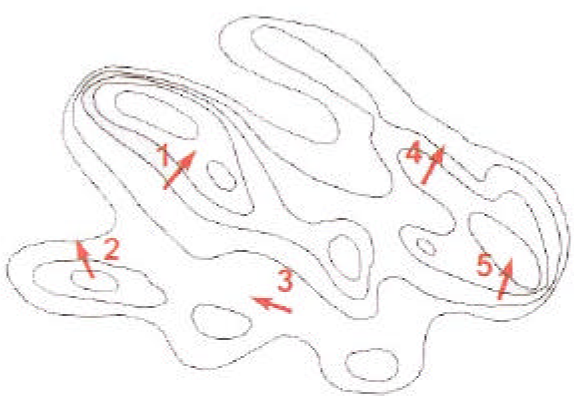
Test Questions

1. If you measure 5 mm on a map to scale of 1:10 000, how many meters is that in reality?

2. Which one of the below is the symbol for railway?

a)  b)  c) d)  

3. Some arrows have been drawn on the map and given a number. State whether the terrain goes upwards, downwards or flat in the direction the arrows are pointing.




1:

2:

3:

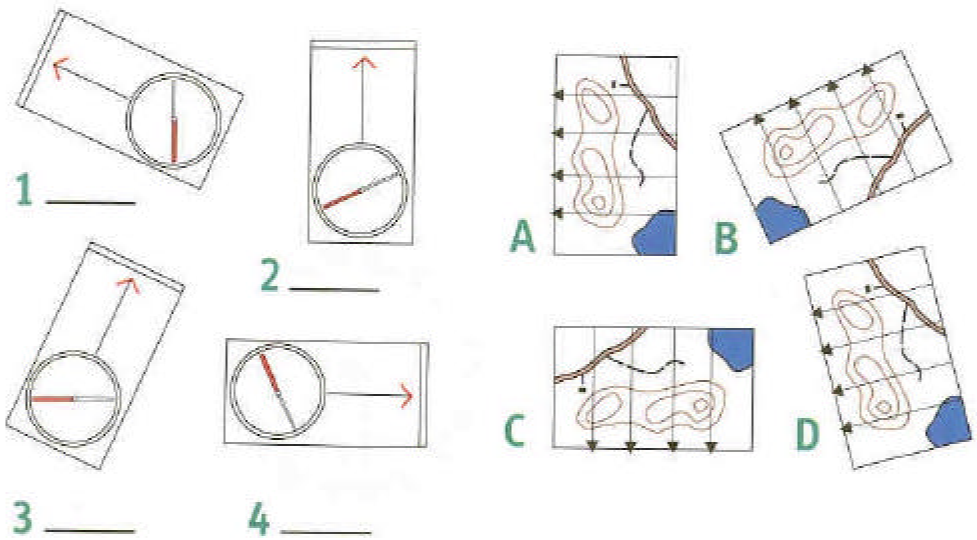
4:

5:

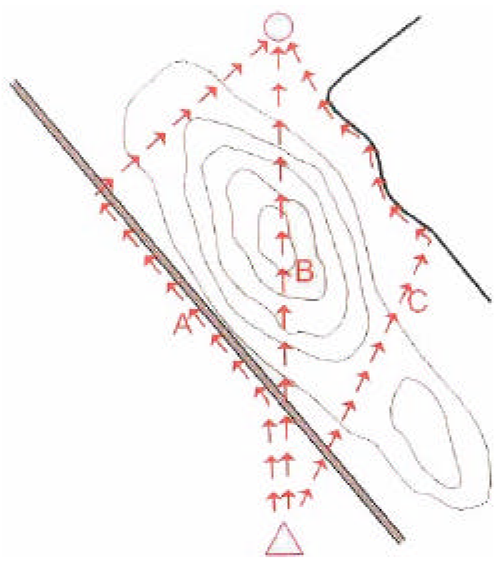
4. In the northern hemisphere of the world at 6 am the sun is in the east, at noon in the south and 6 pm in the west.

TRUE FALSE

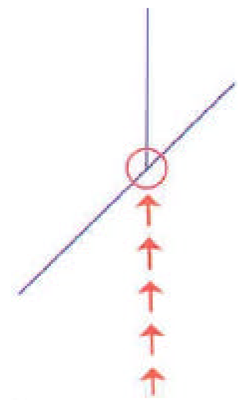
5. Which of the following maps is orientated with which compass?

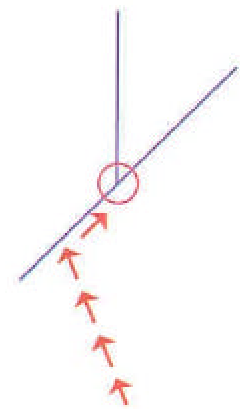



6. In the picture on the right, three different routes are marked. (The starting point is marked with a triangle and the destination with a circle.) Which one would you choose? The criterion is choosing the least tiring, and least risky route to get lost.



7. Your aim point is the fork of these two roads in blue.
Which route do you choose?





8. What is an attack point?

That’s all folks

# APPENDIX F. DISTANCE AZIMUTH CHARTS

## 1. GENERAL

The charts in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. This appendix consists of two documents: Distance azimuth chart for the training field, and the distance azimuth chart for the experiment field.

## 2. TRAINING FIELD DISTANCE AZIMUTH CHART

| | LEG | AZIMUTH | DISTANCE (m) | DISTANCE (Pace) |
|---|---|---|---|---|
| **Start** | | | | |
| | **Leg 1** | **130°** | **21 m** | **12** |
| | **Leg 2** | **090°** | **73 m** | **44** |
| | **Leg 3** | **050°** | **42 m** | **25** |
| | **Leg 4** | **070°** | **67 m** | **40** |
| | **Leg 5** | **038°** | **42 m** | **26** |
| **Check 1** | | | | |
| | **Leg 1** | **000°** | **25 m** | **15** |
| | **Leg 2** | **048°** | **54 m** | **35** |
| | **Leg 3** | **295°** | **80 m** | **47** |
| | **Leg 4** | **234°** | **168 m** | **100** |
| | **Leg 5** | **310°** | **42 m** | **25** |
| | **Leg 6** | **272°** | **88 m** | **52** |
| **Check 2** | | | | |
| | **Leg 1** | **166°** | **20 m** | **12** |
| | **Leg 2** | **244°** | **46 m** | **27** |
| | **Leg 3** | **195°** | **29 m** | **17** |
| | **Leg 4** | **205°** | **51 m** | **30** |
| **Check 3** | | | | |
| | **Leg 1** | **063°** | **72 m** | **43** |
| | **Leg 2** | **006°** | **28 m** | **16** |
| | **Leg 3** | **031°** | **34 m** | **20** |
| | **Leg 4** | **005°** | **27 m** | **16** |
| | **Leg 5** | **069°** | **51 m** | **30** |
| | **Leg 6** | **000°** | **38 m** | **22** |
| | **Leg 7** | **050°** | **63 m** | **37** |
| **Check 4** | | | | |

## 3. EXPERIMENT FIELD DISTANCE AZIMUTH CHART

| | LEG | AZIMUTH | DISTANCE (m) | DISTANCE (Pace) |
|---|---|---|---|---|
| START | | | | |
| | Leg 1 | 224° | 1117 m | 70 |
| | Leg 2 | 203° | 44 m | 26 |
| | Leg 3 | 275° | 72 m | 43 |
| | Leg 4 | 320° | 28 m | 16 |
| Check 1 | | | | |
| | Leg 1 | 305° | 47 m | 28 |
| | Leg 2 | 260° | 96 m | 57 |
| | Leg 3 | 320° | 21 m | 12 |
| Check 2 | | | | |
| | Leg 1 | 235° | 76 m | 45 |
| | Leg 2 | 265° | 93 m | 55 |
| Check 3 | | | | |
| | Leg 1 | 250° | 109 m | 65 |
| | Leg 2 | 232° | 76 m | 45 |
| | Leg 3 | 238° | 56 m | 33 |
| | Leg 4 | 232° | 59 m | 35 |
| | Leg 5 | 190° | 56 m | 33 |
| Check 4 | | | | |
| | Leg 1 | 272° | 50 m | 30 |
| | Leg 2 | 285° | 90 m | 54 |
| Check 5 | | | | |
| | Leg 1 | 177° | 103 m | 61 |
| | Leg 2 | 237° | 84 m | 50 |
| | Leg 3 | 200° | 25 m | 18 |
| Check 6 | | | | |
| | Leg 1 | 345° | 25 m | 15 |
| | Leg 2 | 265° | 45 m | 27 |
| | Leg 3 | 190° | 194 m | 115 |
| | Leg 4 | 101° | 38 m | 22 |

| | LEG | AZIMUTH | DISTANCE (m) | DISTANCE (Pace) |
|---|---|---|---|---|
| | Leg 5 | 082° | 50 m | 30 |
| | Leg 6 | 080° | 55 m | 33 |
| | Leg 7 | 005° | 25 m | 15 |
| | Leg 8 | 085° | 75 m | 45 |
| | Leg 9 | 090° | 50 m | 30 |
| | Leg 10 | 065° | 101 m | 60 |
| | Leg 11 | 157° | 38 m | 22 |
| | Leg 12 | 130° | 75 m | 45 |
| | Leg 13 | 245° | 93 m | 55 |
| Check 7 | | | | |
| | Leg 1 | 065° | 118 m | 70 |
| | Leg 2 | 050° | 57 m | 34 |
| | Leg 3 | 350° | 72 m | 45 |
| | Leg 4 | 000° | 84 m | 50 |
| | Leg 5 | 265° | 21 m | 16 |
| Check 8 | Leg 1 | 053° | 59 m | 35 |
| | Leg 2 | 359° | 38 m | 22 |
| | Leg 3 | 325° | 77m | 46 |
| | Leg 4 | 065° | 76 m | 48 |
| | Leg 5 | 155° | 67 m | 40 |
| | Leg 6 | 100° | 88 m | 52 |
| | Leg 7 | 075° | 42 m | 25 |
| | Leg 8 | 015° | 14 m | 8 |
| Finish | | | | |

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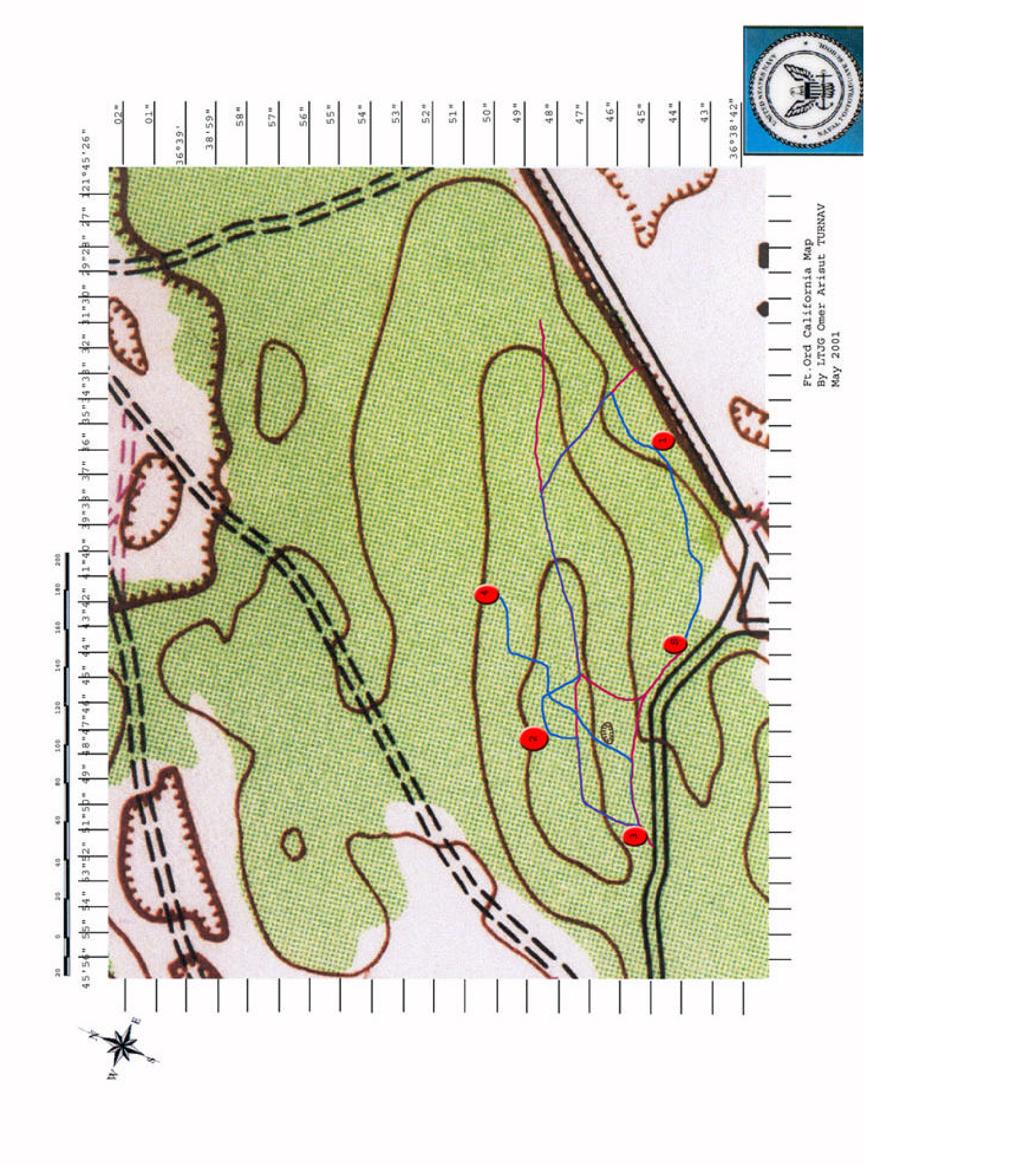
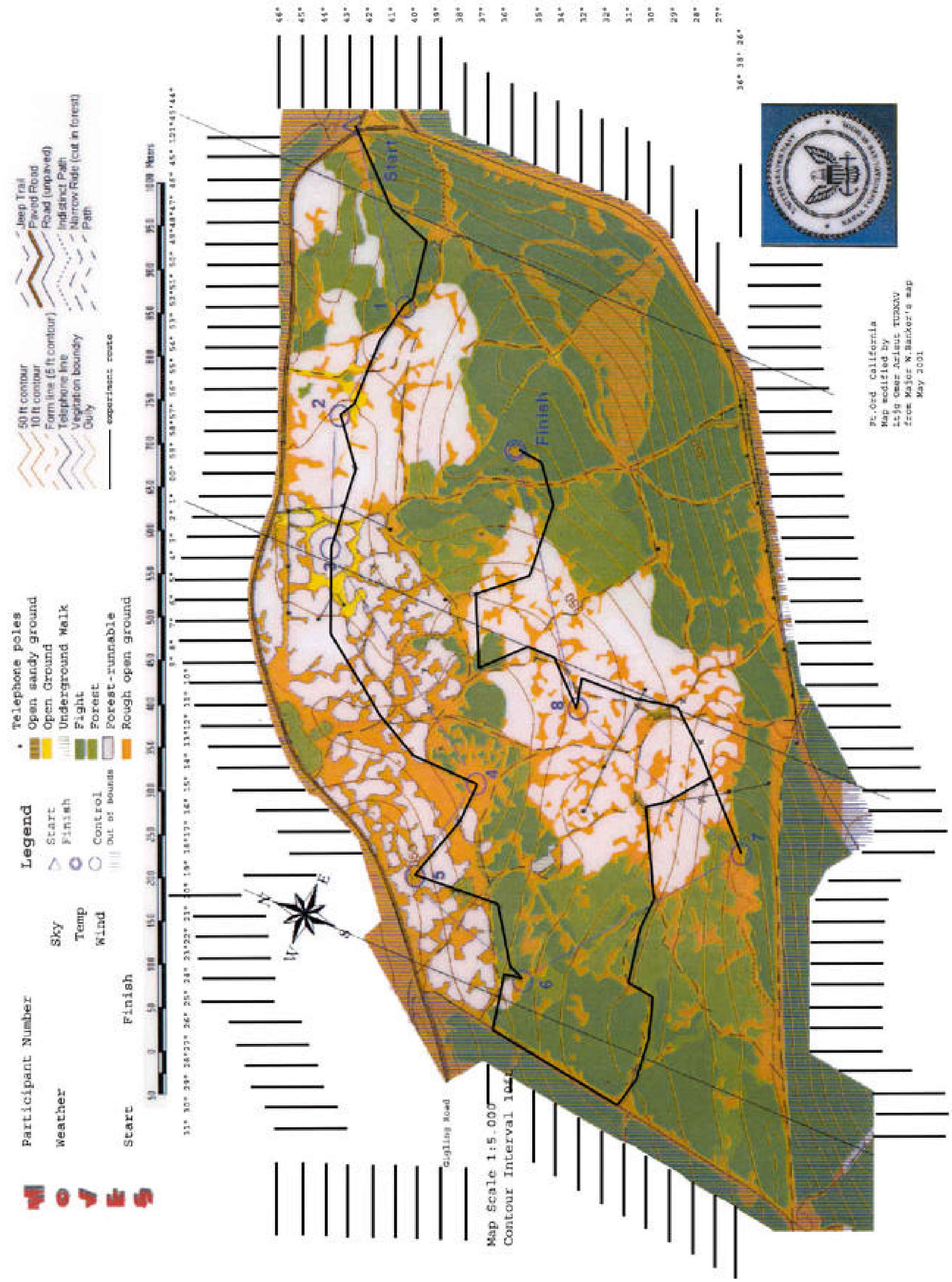
# APPENDIX G. MAPS

## 1. TRAINING FIELD MAP



## 2. EXPERIMENT FIELD MAP



# APPENDIX H. RAW DATA

## 1. GROUP INDIVIDUALS ABILITY CLASSIFICATION MARKS ACCORDING TO SANTA BARBARA SENSE-OF-DIRECTION SCALE. (0-300)

| GPS GROUP | | | M+C GROUP | | |
|---|---|---|---|---|---|
| **Participant ID** | **SPATIAL ABILITY** | **MARK (0-300)** | **Participant ID** | **SPATIAL ABILITY** | **MARK (0-300)** |
| G1 | Good | 204 | MC1 | Excellent | 230 |
| G2 | Excellent | 284 | MC2 | Good | 196 |
| G3 | Good | 182 | MC3 | Weak | 141 |
| G4 | Good | 172 | MC4 | Good | 219 |
| G5 | Very Poor | 62 | MC5 | Good | 222 |
| G6 | Excellent | 250 | MC6 | Weak | 150 |

Scale:

0 – 75 : Very Poor
76 – 150 : Weak
151 – 225 : Good
226 – 300 : Excellent

## 2. GPS GROUP GPS SESSION CHECK POINT COMPLETION TIMES (SEC)

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| Check points | G1 (G) | G2 (E) | G3 (G) | G4 (G) | G5 (VP) | G6 (E) |
| 1 | 87.90 | 100.85 | 94.10 | 102.53 | 101.00 | 95.30 |
| 2 | 38.11 | 29.50 | 38.87 | 33.26 | 43.38 | 37.93 |
| 3 | 50.54 | 49.70 | 50.29 | 54.69 | 63.20 | 57.64 |
| 4 | 27.87 | 26.62 | 31.62 | 18.82 | 39.82 | 28.77 |
| 5 | 47.49 | 39.16 | 42.70 | 37.02 | 48.68 | 37.80 |
| 6 | 112.93 | 61.06 | 118.72 | 96.70 | 82.00 | 78.32 |
| 7 | 14.20 | 34.40 | 22.99 | 18.56 | 19.43 | 19.89 |
| 8 | 84.79 | 82.86 | 88.48 | 119.16 | 81.55 | 66.64 |
| 9 | 65.40 | 74.39 | 80.44 | 81.74 | 76.28 | 82.51 |
| 10 | 66.82 | 65.67 | 86.77 | 76.30 | 96.47 | 108.72 |
| 11 | 46.32 | 47.16 | 52.53 | 47.43 | 62.31 | 49.46 |
| 12 | 40.26 | 43.99 | 47.61 | 42.87 | 51.55 | 50.46 |
| 13 | 46.87 | 46.70 | 46.27 | 60.90 | 59.77 | 52.50 |
| 14 | 46.00 | 47.29 | 57.27 | 59.73 | 44.94 | 54.95 |
| 15 | 32.28 | 61.52 | 47.28 | 36.06 | 47.25 | 64.22 |
| 16 | 72.55 | 82.51 | 95.94 | 78.62 | 77.64 | 78.90 |

### 3. MAP+COMPASS GROUP GPS SESSION CHECK POINT COMPLETION TIMES (SEC)

| | SUBJECTS | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **M1 (E)** | **M2 (G)** | **M3 (W)** | **M4 (G)** | **M5 (G)** | **M6 (W)** |
| 1 | 106.52 | 107.55 | 115.64 | 90.07 | 155.13 | 104.06 |
| 2 | 53.07 | 35.09 | 34.70 | 67.63 | 31.93 | 37.71 |
| 3 | 93.67 | 51.93 | 63.52 | 87.45 | 68.08 | 56.85 |
| 4 | 39.29 | 35.19 | 47.31 | 54.57 | 56.77 | 35.32 |
| 5 | 67.19 | 42.88 | 68.56 | 52.71 | 49.93 | 53.41 |
| 6 | 107.76 | 111.42 | 97.32 | 71.85 | 85.20 | 91.37 |
| 7 | 22.47 | 17.14 | 30.43 | 31.31 | 27.57 | 20.74 |
| 8 | 95.39 | 115.81 | 93.51 | 101.53 | 96.04 | 82.84 |
| 9 | 112.25 | 89.80 | 106.47 | 113.15 | 92.87 | 96.57 |
| 10 | 122.98 | 84.80 | 101.06 | 96.21 | 99.31 | 90.06 |
| 11 | 69.55 | 60.24 | 63.05 | 57.16 | 51.64 | 54.40 |
| 12 | 51.07 | 48.96 | 54.43 | 41.72 | 39.24 | 49.01 |
| 13 | 61.05 | 69.94 | 65.03 | 56.00 | 52.03 | 75.88 |
| 14 | 78.98 | 52.25 | 62.67 | 37.59 | 55.38 | 52.27 |
| 15 | 72.98 | 59.67 | 50.14 | 41.26 | 64.50 | 46.04 |
| 16 | 99.51 | 82.64 | 91.47 | 96.95 | 86.25 | 87.36 |

**4. GPS GROUP MAP+COMPASS SESSION CHECK POINT COMPLETION TIMES (SEC)**

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **G1 (G)** | **G2 (E)** | **G3 (G)** | **G4 (G)** | **G5 (VP)** | **G6 (E)** |
| 17 | 115.28 | 109.38 | 123.17 | 108.10 | 111.39 | 108.41 |
| 18 | 63.20 | 61.91 | 72.31 | 60.56 | 65.92 | 62.43 |
| 19 | 25.33 | 32.81 | 33.78 | 27.69 | 43.13 | 27.52 |
| 20 | 32.96 | 28.14 | 27.40 | 20.48 | 22.99 | 21.78 |
| 21 | 35.68 | 55.97 | 44.24 | 34.95 | 37.19 | 33.36 |
| 22 | 137.45 | 133.85 | 145.25 | 140.56 | 156.44 | 137.30 |
| 23 | 22.75 | 45.88 | 38.76 | 31.38 | 55.01 | 29.26 |
| 24 | 35.20 | 84.94 | 41.34 | 32.43 | 43.38 | 44.20 |
| 25 | 46.71 | 57.49 | 53.93 | 45.57 | 48.37 | 49.69 |
| 26 | 18.76 | 17.40 | 28.13 | 22.28 | 21.33 | 18.41 |
| 27 | 63.33 | 69.47 | 95.51 | 70.10 | 62.62 | 59.47 |
| 28 | 38.13 | 90.65 | 43.71 | 47.34 | 45.67 | 51.41 |
| 29 | 73.16 | 78.10 | 91.37 | 76.78 | 80.22 | 77.24 |
| 30 | 36.33 | 35.81 | 38.55 | 33.82 | 32.47 | 35.28 |
| 31 | 117.00 | 79.96 | 163.07 | 98.07 | 89.04 | 79.24 |
| 32 | 68.80 | 73.16 | 70.99 | 65.64 | 72.09 | 66.23 |
| 33 | 87.15 | 116.13 | 91.72 | 106.59 | 89.78 | 129.88 |
| 34 | 42.14 | 39.70 | 40.15 | 40.36 | 47.15 | 41.30 |
| 35 | 50.60 | 70.30 | 60.83 | 74.43 | 59.89 | 50.99 |
| 36 | 70.04 | 62.28 | 56.77 | 63.98 | 61.12 | 70.28 |
| 37 | 14.60 | 17.58 | 29.16 | 27.12 | 25.69 | 21.40 |
| 38 | 67.79 | 63.54 | 62.66 | 109.80 | 81.29 | 55.98 |
| 39 | 24.90 | 27.99 | 34.46 | 26.43 | 25.88 | 33.66 |
| 40 | 54.90 | 69.98 | 65.50 | 63.91 | 60.13 | 70.89 |
| 41 | 58.76 | 75.57 | 61.14 | 65.45 | 66.14 | 65.32 |
| 42 | 69.65 | 62.13 | 75.11 | 70.41 | 67.75 | 54.96 |
| 43 | 197.36 | 89.00 | 91.95 | 80.32 | 104.23 | 90.71 |
| 44 | 52.23 | 54.25 | 38.30 | 49.17 | 38.58 | 41.63 |
| 45 | 10.05 | 10.46 | 12.66 | 12.07 | 14.01 | 11.39 |

**5. MAP+COMPASS GROUP MAP+COMPASS SESSION CHECK POINT COMPLETION TIMES (SEC)**

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **M1 (E)** | **M2 (G)** | **M3 (W)** | **M4 (G)** | **M5 (G)** | **M6 (W)** |
| 17 | 108.98 | 109.51 | 106.19 | 107.79 | 105.45 | 114.27 |
| 18 | 60.14 | 70.51 | 50.42 | 64.48 | 72.13 | 53.65 |
| 19 | 24.26 | 27.09 | 31.04 | 22.87 | 31.33 | 27.51 |
| 20 | 34.34 | 21.34 | 19.43 | 18.95 | 17.60 | 24.96 |
| 21 | 30.05 | 35.04 | 55.91 | 31.48 | 35.94 | 44.82 |
| 22 | 108.91 | 126.18 | 131.61 | 148.32 | 136.55 | 140.45 |
| 23 | 31.46 | 31.13 | 37.82 | 25.93 | 30.15 | 27.39 |
| 24 | 39.44 | 46.86 | 48.79 | 39.29 | 32.61 | 46.80 |
| 25 | 40.93 | 53.60 | 67.59 | 39.24 | 44.45 | 40.68 |
| 26 | 22.26 | 18.06 | 11.26 | 17.82 | 16.98 | 16.02 |
| 27 | 77.82 | 71.82 | 67.05 | 57.21 | 57.65 | 73.47 |
| 28 | 42.18 | 38.12 | 64.96 | 44.33 | 33.32 | 29.79 |
| 29 | 79.61 | 80.73 | 67.76 | 70.22 | 66.09 | 75.26 |
| 30 | 32.14 | 36.92 | 37.06 | 30.73 | 28.34 | 27.50 |
| 31 | 127.15 | 74.99 | 76.72 | 73.90 | 100.03 | 90.88 |
| 32 | 63.40 | 49.66 | 67.18 | 80.58 | 59.27 | 60.48 |
| 33 | 85.06 | 108.22 | 88.84 | 108.04 | 79.24 | 87.59 |
| 34 | 20.21 | 29.11 | 55.02 | 45.06 | 31.08 | 33.12 |
| 35 | 50.04 | 62.93 | 49.53 | 58.48 | 62.82 | 65.36 |
| 36 | 57.41 | 51.45 | 51.45 | 67.87 | 58.34 | 86.12 |
| 37 | 18.04 | 14.63 | 18.39 | 21.80 | 20.08 | 13.27 |
| 38 | 45.82 | 50.78 | 57.80 | 48.70 | 57.14 | 48.01 |
| 39 | 24.69 | 20.80 | 44.28 | 25.64 | 20.87 | 26.45 |
| 40 | 49.84 | 61.37 | 59.99 | 56.35 | 53.70 | 72.06 |
| 41 | 59.27 | 71.40 | 62.07 | 62.66 | 60.28 | 61.30 |
| 42 | 53.59 | 48.83 | 67.68 | 60.07 | 43.50 | 85.06 |
| 43 | 98.49 | 89.10 | 106.66 | 90.97 | 92.46 | 148.93 |
| 44 | 35.37 | 39.31 | 42.34 | 35.07 | 77.45 | 33.11 |
| 45 | 10.20 | 11.36 | 12.63 | 10.38 | 11.25 | 8.98 |

### 6. GPS GROUP GPS SESSION DISTANCE ERRORS (M)

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **G1 (G)** | **G2 (E)** | **G3 (G)** | **G4 (G)** | **G5 (VP)** | **G6 (E)** |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 7. MAP+COMPASS GROUP GPS SESSION DISTANCE ERRORS (M)

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **M1 (E)** | **M2 (G)** | **M3 (W)** | **M4 (G)** | **M5 (G)** | **M6 (W)** |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 8. GPS GROUP MAP+COMPASS SESSION DISTANCE ERRORS (M)

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **G1 (G)** | **G2 (E)** | **G3 (G)** | **G4 (G)** | **G5 (VP)** | **G6 (E)** |
| 17 | 6.00 | 6.00 | 5.00 | 10.00 | 7.00 | 2.00 |
| 18 | 8.00 | 8.00 | 1.00 | 4.00 | 0.00 | 7.00 |
| 19 | 7.00 | 6.00 | 8.00 | 2.00 | 5.00 | 5.00 |
| 20 | 10.00 | 0.00 | 0.00 | 0.00 | 1.00 | 3.00 |
| 21 | 0.00 | 5.00 | 2.00 | 3.00 | 4.00 | 5.00 |
| 22 | 1.00 | 3.00 | 3.00 | 0.00 | 3.00 | 4.00 |
| 23 | 2.00 | 0.00 | 2.00 | 5.00 | 0.00 | 0.00 |
| 24 | 4.00 | 3.00 | 1.00 | 0.00 | 5.00 | 6.00 |
| 25 | 3.00 | 6.00 | 8.00 | 4.00 | 7.00 | 6.00 |
| 26 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| 27 | 7.00 | 2.00 | 5.00 | 1.00 | 6.00 | 8.00 |
| 28 | 0.00 | 2.00 | 2.00 | 0.00 | 15.00 | 2.00 |
| 29 | 2.00 | 7.00 | 5.00 | 4.00 | 0.00 | 0.00 |
| 30 | 5.00 | 2.00 | 6.00 | 4.00 | 3.00 | 3.00 |
| 31 | 8.00 | 3.00 | 2.00 | 3.00 | 4.00 | 5.00 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 | 6.00 | 0.00 |
| 33 | 3.00 | 5.00 | 5.00 | 8.00 | 15.00 | 6.00 |
| 34 | 0.00 | 5.00 | 0.00 | 2.00 | 10.00 | 6.00 |
| 35 | 12.00 | 0.00 | 6.00 | 3.00 | 12.00 | 7.00 |
| 36 | 8.00 | 5.00 | 0.00 | 3.00 | 7.00 | 5.00 |
| 37 | 3.00 | 3.00 | 5.00 | 0.00 | 1.00 | 0.00 |
| 38 | 6.00 | 6.00 | 6.00 | 5.00 | 8.00 | 2.00 |
| 39 | 5.00 | 4.00 | 3.00 | 1.00 | 6.00 | 3.00 |
| 40 | 0.00 | 2.00 | 4.00 | 1.00 | 5.00 | 0.00 |
| 41 | 7.00 | 4.00 | 10.00 | 4.00 | 5.00 | 3.00 |
| 42 | 4.00 | 6.00 | 8.00 | 12.00 | 8.00 | 9.00 |
| 43 | 2.00 | 8.00 | 13.00 | 20.00 | 2.00 | 2.00 |
| 44 | 2.00 | 1.00 | 3.00 | 2.00 | 2.00 | 1.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**9. MAP+COMPASS GROUP MAP+COMPASS SESSION DISTANCE ERRORS (M)**

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| Check points | M1 (E) | M2 (G) | M3 (W) | M4 (G) | M5 (G) | M6 (W) |
| 17 | 2.00 | 3.00 | 2.00 | 0.00 | 0.00 | 2.00 |
| 18 | 2.00 | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 |
| 19 | 0.00 | 2.00 | 1.00 | 0.00 | 2.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 2.00 | 0.00 | 0.00 |
| 21 | 0.00 | 0.00 | 2.00 | 0.00 | 0.00 | 3.00 |
| 22 | 0.00 | 3.00 | 5.00 | 1.00 | 0.00 | 4.00 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| 25 | 0.00 | 0.00 | 2.00 | 2.00 | 2.00 | 0.00 |
| 26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27 | 2.00 | 0.00 | 4.00 | 3.00 | 2.00 | 4.00 |
| 28 | 0.00 | 5.00 | 0.00 | 2.00 | 0.00 | 0.00 |
| 29 | 0.00 | 3.00 | 3.00 | 0.00 | 2.00 | 2.00 |
| 30 | 2.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31 | 1.00 | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 33 | 0.00 | 0.00 | 0.00 | 3.00 | 0.00 | 7.00 |
| 34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 |
| 35 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 |
| 36 | 2.00 | 3.00 | 2.00 | 3.00 | 0.00 | 0.00 |
| 37 | 0.00 | 0.00 | 0.00 | 2.00 | 0.00 | 0.00 |
| 38 | 0.00 | 2.00 | 4.00 | 3.00 | 6.00 | 0.00 |
| 39 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41 | 3.00 | 0.00 | 4.00 | 2.00 | 4.00 | 0.00 |
| 42 | 3.00 | 2.00 | 2.00 | 2.00 | 4.00 | 2.00 |
| 43 | 1.00 | 1.00 | 1.00 | 0.00 | 4.00 | 4.00 |
| 44 | 2.00 | 3.00 | 2.00 | 0.00 | 0.00 | 1.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 10. GPS GROUP GPS SESSION OFF-ROUTE ERRORS

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| Check points | G1 (G) | G2 (E) | G3 (G) | G4 (G) | G5 (VP) | G6 (E) |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| 6 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| 7 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 11. MAP+COMPASS GROUP GPS SESSION OFF-ROUTE ERRORS

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| Check points | M1 (E) | M2 (G) | M3 (W) | M4 (G) | M5 (G) | M6 (W) |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 |
| 2 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 |
| 3 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 |
| 9 | 2.00 | 0.00 | 0.00 | 1.00 | 0.00 | 1.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| 14 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 12. GPS GROUP MAP+COMPASS SESSION OFF-ROUTE ERRORS

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| Check points | G1 (G) | G2 (E) | G3 (G) | G4 (G) | G5 (VP) | G6 (E) |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 28 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| 29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 33 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 |
| 34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 37 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 38 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| 39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| 42 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| 43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 13. MAP+COMPASS GROUP MAP+COMPASS SESSION OFF-ROUTE ERRORS

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **M1 (E)** | **M2 (G)** | **M3 (W)** | **M4 (G)** | **M5 (G)** | **M6 (W)** |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 37 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 14. GPS GROUP GPS SESSION NORMALIZED TASK COMPLETION TIMES (SEC)

| | SUBJECTS | | | | | |
|---|---|---|---|---|---|---|
| Check points | G1 (G) | G2 (E) | G3 (G) | G4 (G) | G5 (VP) | G6 (E) |
| 1 | 125.57 | 144.07 | 134.43 | 146.47 | 144.29 | 136.14 |
| 2 | 146.58 | 113.46 | 149.50 | 127.92 | 166.85 | 145.88 |
| 3 | 117.53 | 115.58 | 116.95 | 127.19 | 146.98 | 134.05 |
| 4 | 174.19 | 166.38 | 197.63 | 117.63 | 248.87 | 179.81 |
| 5 | 169.61 | 139.86 | 152.50 | 132.21 | 173.86 | 135.00 |
| 6 | 198.12 | 107.12 | 208.28 | 169.65 | 143.86 | 137.40 |
| 7 | 118.33 | 286.67 | 191.58 | 154.67 | 161.92 | 165.75 |
| 8 | 188.42 | 184.13 | 196.62 | 264.80 | 181.22 | 148.09 |
| 9 | 118.91 | 135.25 | 146.25 | 148.62 | 138.69 | 150.02 |
| 10 | 102.80 | 101.03 | 133.49 | 117.38 | 148.42 | 167.26 |
| 11 | 102.93 | 104.80 | 116.73 | 105.40 | 138.47 | 109.91 |
| 12 | 122.00 | 133.30 | 144.27 | 129.91 | 156.21 | 152.91 |
| 13 | 133.91 | 133.43 | 132.20 | 174.00 | 170.77 | 150.00 |
| 14 | 139.39 | 143.30 | 173.55 | 181.00 | 136.18 | 166.52 |
| 15 | 107.60 | 205.07 | 157.60 | 120.20 | 157.50 | 214.07 |
| 16 | 134.35 | 152.80 | 177.67 | 145.59 | 143.78 | 146.11 |

## 15. MAP + COMPASS GROUP GPS SESSION NORMALIZED TASK COMPLETION TIMES (SEC)

| SUBJECTS | | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **G1 (G)** | **G2 (E)** | **G3 (G)** | **G4 (G)** | **G5 (VP)** | **G6 (E)** |
| 1 | 152.17 | 153.64 | 165.20 | 128.67 | 221.61 | 148.66 |
| 2 | 204.12 | 134.96 | 133.46 | 260.12 | 122.81 | 145.04 |
| 3 | 217.84 | 120.77 | 147.72 | 203.37 | 158.33 | 132.21 |
| 4 | 245.56 | 219.94 | 295.69 | 341.06 | 354.81 | 220.75 |
| 5 | 239.96 | 153.14 | 244.86 | 188.25 | 178.32 | 190.75 |
| 6 | 189.05 | 195.47 | 170.74 | 126.05 | 149.47 | 160.30 |
| 7 | 187.25 | 142.83 | 253.58 | 260.92 | 229.75 | 172.83 |
| 8 | 211.98 | 257.36 | 207.80 | 225.62 | 213.42 | 184.09 |
| 9 | 204.09 | 163.27 | 193.58 | 205.73 | 168.85 | 175.58 |
| 10 | 189.20 | 130.46 | 155.48 | 148.02 | 152.78 | 138.55 |
| 11 | 154.56 | 133.87 | 140.11 | 127.02 | 114.76 | 120.89 |
| 12 | 154.76 | 148.36 | 164.94 | 126.42 | 118.91 | 148.52 |
| 13 | 174.43 | 199.83 | 185.80 | 160.00 | 148.66 | 216.80 |
| 14 | 239.33 | 158.33 | 189.91 | 113.91 | 167.82 | 158.39 |
| 15 | 243.27 | 198.90 | 167.13 | 137.53 | 215.00 | 153.47 |
| 16 | 184.28 | 153.04 | 169.39 | 179.54 | 159.72 | 161.78 |

## 16. GPS GROUP MAP+COMPASS SESSION NORMALIZED TASK COMPLETION TIMES (SEC)

| | SUBJECTS | | | | | |
|---|---|---|---|---|---|---|
| Check points | G1 (G) | G2 (E) | G3 (G) | G4 (G) | G5 (VP) | G6 (E) |
| 17 | 188.98 | 179.31 | 201.92 | 177.21 | 182.61 | 177.72 |
| 18 | 126.40 | 123.82 | 144.62 | 121.12 | 131.84 | 124.86 |
| 19 | 140.72 | 182.28 | 187.67 | 153.83 | 239.61 | 152.89 |
| 20 | 219.73 | 187.60 | 182.67 | 136.53 | 153.27 | 145.20 |
| 21 | 132.15 | 207.30 | 163.85 | 129.44 | 137.74 | 123.56 |
| 22 | 119.52 | 116.39 | 126.30 | 122.23 | 136.03 | 119.39 |
| 23 | 103.41 | 208.55 | 176.18 | 142.64 | 250.05 | 133.00 |
| 24 | 117.33 | 283.13 | 137.80 | 108.10 | 144.60 | 147.33 |
| 25 | 141.55 | 174.21 | 163.42 | 138.09 | 146.58 | 150.58 |
| 26 | 125.07 | 116.00 | 187.53 | 148.53 | 142.20 | 122.73 |
| 27 | 140.73 | 154.38 | 212.24 | 155.78 | 139.16 | 132.16 |
| 28 | 127.10 | 302.17 | 145.70 | 157.80 | 152.23 | 171.37 |
| 29 | 121.93 | 130.17 | 152.28 | 127.97 | 133.70 | 128.73 |
| 30 | 165.14 | 162.77 | 175.23 | 153.73 | 147.59 | 160.36 |
| 31 | 260.00 | 177.69 | 362.38 | 217.93 | 197.87 | 176.09 |
| 32 | 125.09 | 133.02 | 129.07 | 119.35 | 131.07 | 120.42 |
| 33 | 124.50 | 165.90 | 131.03 | 152.27 | 128.26 | 185.54 |
| 34 | 123.94 | 116.76 | 118.09 | 118.71 | 138.68 | 121.47 |
| 35 | 112.44 | 156.22 | 135.18 | 165.40 | 133.09 | 113.31 |
| 36 | 140.08 | 124.56 | 113.54 | 127.96 | 122.24 | 140.56 |
| 37 | 91.25 | 109.88 | 182.25 | 169.50 | 160.56 | 133.75 |
| 38 | 193.69 | 181.54 | 179.03 | 313.71 | 232.26 | 159.94 |
| 39 | 113.18 | 127.23 | 156.64 | 120.14 | 117.64 | 153.00 |
| 40 | 119.35 | 152.13 | 142.39 | 138.93 | 130.72 | 154.11 |
| 41 | 122.42 | 157.44 | 127.38 | 136.35 | 137.79 | 136.08 |
| 42 | 174.13 | 155.33 | 187.77 | 176.03 | 169.38 | 137.40 |
| 43 | 379.54 | 171.15 | 176.83 | 154.46 | 200.44 | 174.44 |
| 44 | 208.92 | 217.00 | 153.20 | 196.68 | 154.32 | 166.52 |
| 45 | 125.63 | 130.75 | 158.25 | 150.87 | 175.12 | 142.37 |

## 17. MAP+COMPASS GROUP MAP+COMPASS SESSION NORMALIZED TASK COMPLETION TIMES (SEC)

| | SUBJECTS | | | | | |
|---|---|---|---|---|---|---|
| **Check points** | **G1 (G)** | **G2 (E)** | **G3 (G)** | **G4 (G)** | **G5 (VP)** | **G6 (E)** |
| 17 | 178.66 | 179.52 | 174.08 | 176.70 | 172.87 | 187.33 |
| 18 | 120.28 | 141.02 | 100.84 | 128.96 | 144.26 | 107.30 |
| 19 | 134.78 | 150.50 | 172.44 | 127.06 | 174.06 | 152.83 |
| 20 | 228.93 | 142.27 | 129.53 | 126.33 | 117.33 | 166.40 |
| 21 | 111.30 | 129.78 | 207.07 | 116.59 | 133.11 | 166.00 |
| 22 | 94.70 | 109.72 | 114.44 | 128.97 | 118.74 | 122.13 |
| 23 | 143.00 | 141.50 | 171.91 | 117.86 | 137.05 | 124.50 |
| 24 | 131.47 | 156.20 | 162.63 | 130.97 | 108.70 | 156.00 |
| 25 | 124.03 | 162.42 | 204.82 | 118.91 | 134.70 | 123.27 |
| 26 | 148.40 | 120.40 | 75.07 | 118.80 | 113.20 | 106.80 |
| 27 | 172.93 | 159.60 | 149.00 | 127.13 | 128.11 | 163.27 |
| 28 | 140.60 | 127.07 | 216.53 | 147.77 | 111.07 | 99.30 |
| 29 | 132.68 | 134.55 | 112.93 | 117.03 | 110.15 | 125.43 |
| 30 | 146.09 | 167.82 | 168.45 | 139.68 | 128.82 | 125.00 |
| 31 | 282.56 | 166.64 | 170.49 | 164.22 | 222.29 | 201.96 |
| 32 | 115.27 | 90.29 | 122.15 | 146.51 | 107.76 | 109.96 |
| 33 | 121.51 | 154.60 | 126.91 | 154.34 | 113.20 | 125.13 |
| 34 | 59.44 | 85.62 | 161.82 | 132.53 | 91.41 | 97.41 |
| 35 | 111.20 | 139.84 | 110.07 | 129.96 | 139.60 | 145.24 |
| 36 | 114.82 | 102.90 | 102.90 | 135.74 | 116.68 | 172.24 |
| 37 | 112.75 | 91.44 | 114.94 | 136.25 | 125.50 | 82.94 |
| 38 | 130.91 | 145.09 | 165.14 | 139.14 | 163.26 | 137.17 |
| 39 | 112.23 | 94.55 | 201.27 | 116.55 | 94.86 | 120.23 |
| 40 | 108.35 | 133.41 | 130.41 | 122.50 | 116.74 | 156.65 |
| 41 | 123.48 | 148.75 | 129.31 | 130.54 | 125.58 | 127.71 |
| 42 | 133.98 | 122.08 | 169.20 | 150.18 | 108.75 | 212.65 |
| 43 | 189.40 | 171.35 | 205.12 | 174.94 | 177.81 | 286.40 |
| 44 | 141.48 | 157.24 | 169.36 | 140.28 | 309.80 | 132.44 |
| 45 | 127.50 | 142.00 | 157.88 | 129.75 | 140.63 | 112.25 |

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